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Final Report On Biotechnology Research Requirements For Aeronautical Systems Through The Year 2000

Volume I

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Preface

The purpose of this study is to identify basic and applied life sciences research needed to support Air Force aeronautical systems that could be in development or operation by the year 2000 and beyond. This research should serve both near and far-term goals.

Technological advances applied to aircraft and weapons, the quantity and rate of information flow through the cockpit, and the environment in which the pilot will operate will produce high-stress missions requiring increased human performance. These same technological advances may also present new burdens on elements of the command and control system, posing new demands on ground or air-based command and control systems.

A mission can be considered high-stress when the demands imposed on the crew approach their capacities; this generalization applies to such diverse demand-capacity relationships as strength, sweat production, maximum cardio-respiratory fitness, cognitive processes and visuo-motor reactions. When high stress occurs as a result of a mismatch between the demands of the mission and the capacities of the individual, there are four possible remedies:

- ☐ modify the individual
- ☐ modify the equipment
- ☐ modify the task demands
- ☐ a combination of the above

The biotechnology portion of this report treats all four of these approaches. The study identifies those key areas where research is required concerning human protection (both physical and mental), suggests the questions to be asked, and cites some approaches that appear promising.

The answers to these questions will guide the matching of pilots to aircraft and will influence the very nature of the crew members' role by the year 2000 and beyond.

This study brought together engineers and biotechnologists to discuss the problems of the year 2000 aircrewman. The engineers, in their Engineering Core Committee, examined the trends and possible developments in airframes, power plants, weapons, avionics, and threats that could be in operational aircraft or included in aircraft under development by the year 2000. The Engineering Core Committee prepared, as a result of these discussions, a set of mission profiles for tactical, strategic and other missions. These missions, discussed in Chapter 1, were presented to and discussed with the Biotechnology Core Committee in a joint meeting at Southwest Research Institute in September, 1981.

The Biotechnology Core Committee, after study of these recommendations, identified six (later expanded to seven) areas of biotechnology that would be most affected by hardware developments and the changes in mission requirements. The Biotechnology Core Committee selected additional experts to serve on study groups of these six areas of biotechnology at a Study Session held in San Antonio in January, 1982.

These study groups were charged with identifying the specific research issues that must be addressed by the Air Force to meet the biotechnology requirements of the year 2000 aircrew. Further, a plan for pursuing these research topics was to be developed. The results of these study groups' efforts constitute this report.

Biotechnology is such a diverse and complex field that any one of the selected study areas could have warranted its own, individual report. To best serve the aircrew, however, they must be considered together so that a properly integrated system of support, control and communications can be provided that enables the aircrew to optimally perform their mission.

Because of the volume of material needed to fully address the recommended research, this report is presented in two parts. Volume I is a summary overview of the aeronautical systems of the future and the biotechnology research required to meet the needs of the aircrew. Volume II discusses each of the study areas in the detail needed to justify the commitment of resources to the solution of the identified problems.

Acknowledgments

This report is the result of the efforts and enthusiastic participation of a diverse group of biotechnologists drawn from academia, private business, government and the military. We gratefully acknowledge the following committee members for their contributions. The full names and addresses of these participants can be found in Appendix A.

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Abstract

This report discusses the basic biotechnology research problems that require solution by the year 2000 to ensure optimum performance of manned Air Force aeronautical systems. The projected aeronautical systems for strategic, tactical and support systems are discussed, with emphasis placed on the roles of increased automation and information processing, as well as the increased physical stress of higher performance aircraft, extended mission durations and new weapon threats. Six generic areas of biotechnology are considered, along with the research needed to address the needs of the year 2000 aircrew. First discussed is the human-machine symbiosis needed in systems that will become extraordinarily complex. This is followed by the related needs in developing improved human-machine information interfaces that avoid overloading the human operator or pilot. Many missions of the future will be unforgiving and of high intensity. The problems and research needed to deal with the increased stress and to protect and enhance aircrews' performance during these missions are discussed in detail. The report discusses how simulators can be advanced to provide not only better training for aircrews, but also how they can be used in the development of new systems for optimizing the human-information-machine relationship. The increasing complexity of aeronautical systems discussed early in the report is complemented by a chapter on crew selection and enhancement. More care and better techniques are needed for selecting candidates for each aircrew position and for enhancing their capabilites in order to maximize their potential for successfully accomplishing their missions. The report is completed by chapters on the problems and research issues facing aircrews who must operate in chemical and biological warfare environments and in radiation environments.

The breadth of topics covered in this study required that the report be published in two volumes. Volume 1 is a very brief summary of the research issues and the proposed research plan. Volume 2 provides, for the interested reader, a more detailed discussion on the background and proposed solutions of each of the research issues.

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Introduction

From the beginning of recorded history to the present time, man has played a key role in the performance of the weapon systems at his disposal. Initially, his physical capabilities were the critical factors in his role in the weapon system; however, his decision-making abilities have now become equally important. This change has been evolutionary, thus existing systems do not necessarily take full advantage of man and his unique skills. This shortcoming has been triggered in part by the absence of a sufficient biotechnology base to allow informed improvements in system design to be made in concert with other technological advances.

Definition of the Problem

Stated simply, technology threatens to outstrip man's ability to cope on both a physical and mental level. New power plants and materials have made possible aircraft that can maintain high sustained G-loads that exceed man's tolerance; protection of man from various threats produce physiologic and psychological stresses that overwhelm the body's normal defense mechanisms; and avionics technology has produced the capability to generate information with a data rate that easily saturates the comprehension and decision-making ability of the aircrews.

The concern of this study is to understand the overloads implicit in future engineering developments. The goal is to define those research strategies required to make maximum utilization of both human and technological capabilities in future aeronautical systems.

Scope of the Study

Biotechnology requirements are broad. In order to place some limits, these requirements have been bounded by consideration of engineering technologies thought to be available by the year 2000, and by consideration of the various types of aeronautical missions that these engineering technologies should make possible. The following topics are addressed:

- ☐ Aeronautical Systems Projections, 1990-2020
- ☐ Human-Machine Symbiosis with Extraordinarily Complex Systems
- ☐ Human-Machine Information Interfaces
- ☐ High Intensity, Unforgiving Missions—Mission Stress, Protection and Performance Enhancement
- ☐ Simulation
- ☐ Crew Selection and Enhancement
- ☐ Chemical and Biological Defense
- ☐ Radiation Environment

Space systems per se, while important in the time under consideration, are excluded from consideration.

Executive Summary

It is a truism that aircraft and their use in the military are evolving rapidly, whereas the pilots and crew are evolving hardly at all. Another truism, although frequently disregarded, is that the pilot is an essential element in any manned weapons system; his performance and protection must be accounted for during initial design, and not as an afterthought.

Looking to the year 2000 and beyond, we can expect aircraft that fly higher and faster, withstand higher G-loads and maneuver rapidly in all axes, remain aloft longer and serve as semi-autonomous command centers, and fly close to the ground and in high turbulence. Furthermore, they will be subjected to new threats from chemical, biological and radiation weapons. The principal role of the pilot will change to one of decision-maker and systems manager of a complex man-computer partnership. It would be a tragic mistake to wait until such vehicles were made operational before attacking those biotechnology problems that are potentially the Achilles heel of such advanced systems. A long-range program of basic and applied research in biotechnology should be aimed at identifying the potential problems and suggesting and validating candidate solutions. Having identified the problem areas, research can be directed toward identification of human limitations in the projected operational environment, the selection and training to optimize performance, the design of man-machine interfaces to achieve reliability and flexibility, and development of protective measures to enable the crew as well as the aircraft to survive.

In order to identify the major problem areas and plot basic research strategy, a Biotechnology Study Group was formed. The organization included an Engineering Technology Panel to define and advise on mission scenarios, and six Biotechnology Panels to define specific research topics to meet the needs associated with these missions. The following report contains abbreviated versions of the extensive research strategy recommendations made by the panels following a one-week study session in San Antonio during January 1982. A complete proceeding of this study session is published as Volume 2 of this report.

The role of the pilot in the future mission scenarios considered in this report differs substantially from his current role, to wit: information processing and decision-making, mission stresses associated with duration and acceleration, and protection against CBR threats. Whereas the latter two categories are extensions into newer domains of problems that are currently recognized, the first area represents a dramatic new departure. Automation in the cockpit is a reality, but the ways to use automation are by no means understood. Research programs are outlined for man-computer symbiosis, including new initiatives for two-way communication with machines and use of computer-aided decision-making in the cockpit. The management of several sources of information and its relationship to pilot workload is an area requiring extensive research. Research initiatives in non-conventional control modalities, including further use of voice commands, electromyogram and evoked-response controls, are suggested.

Enhancement of performance in unfriendly environments through the use of robotic systems and extension of stand-off weapons systems requires considerable research in terms of the human interface.

Research strategies are outlined to deal with the pervasive issue of monitoring and modeling of human performance under stress. Performance measures and models in the past, reflecting older technology, concentrated on the human as an element in a continuous control loop, whereas the emphasis for performance of the pilot in the year 2000 must be increasingly on his role as a systems manager. Modeling of the effects of environmental stressors on human performance, and especially the interactions associated with multiple stressors, represents a prime area for basic research in biotechnology. Problems of spatial disorientation and motion sickness will become more serious unless new approaches to training, aircraft design or pilot protection are achieved. Pilot protection from the stresses of unforgiving missions should take several avenues, including pharmacological approaches, research on high-G and vibration protection to reduce physiological reactions and biodynamic coupling, and early development work on a new generation of suits, helmets and escape systems. Research toward the approach of pilot protection and from the aerospace environment as an integrated systems problem, rather than a series of additional patches to the suit or helmet in response to each threat, is recommended.

The nature of missions envisioned by the year 2000 and beyond, as well as the cost associated with training in the air, indicate a substantial increase in the use of full or part task-trainers and simulation in pilot training. Major research initiatives are required to improve our understanding of flight simulator requirements and their effectiveness. In particular, the area of motion cues, their necessity and the ways of maximizing their utility need additional research. Visual augmentation through innovative use of external scene generation is another promising area for research in which the technology that currently exists is well ahead of our knowledge about how it should be applied. A closely related area associated with training is one of crew selection and enhancement. The frequently discussed notion of multiple track selection of Air Force pilots should be explored through a full-fledged training research program, since potential benefits are significant. In conjunction, we must improve our means of pilot evaluation and feedback of these evaluations at various stages of training to validate training effectiveness and the appropriateness of pilot selection criteria.

Consistent with the changing pilot role, selection criteria should be expanded to take into account appropriate measures of cognitive styles, an area where considerable research would be required before results could be implemented. Among a number of open issues in crew selection, attention is called to the need for research concerning individual variations in circadian rhythm patterns and their relationship to long or changing duty cycles. Crew enhancement research should be directed at sensory enhancement, especially visual, and the associated development of visual performance measurements more relevent to the aviation environment than those currently employed. Additional research is called for on topics related to crew fatigue and techniques for improving performance during long duty hours, including evaluation of relaxation and alerting techniques. Human factors research is required in the area of control and displays, with the possibilities of individualizing them to meet the needs and capabilities of each crew member.

Biological warfare protection will require substantial research in dealing with new biological agents and with the potential impact of genetic engineering approaches. The development of animal models for predicting central nervous system decrements associated with biological or chemical warfare threats is a continuing need, and such models will serve an important role in the evaluation of drug or other prophylaxis or treatment methods and their side effects. The links between physiological responses and behavioral measurements concomitant to CW and BW represents an essential area of basic research. New detectors and field techniques for identification of chemical warfare elements are required. Protection against CW as well as BW can be usefully studied in several new areas, including alternatives to current suits such as a disposable "protective skin" or advanced decontamination techniques. Protection against radiation threats will require research initiatives in two areas. The increasing concern with protection against laser weapons or inadvertent exposure to

lasers requires not only continued study of eye protective devices but more basic research on the medical and performance consequences of laser damage to the eyes. A final line of new research concerns protection against pulsed radio frequence radiation. Models are required to understand the phenomenon at the molecular, cellular and tissue levels.

1

Aeronautical Systems Projections 1990-2020

This section summarizes the conclusions of the Engineering Core Committee which were used by the Biotechnology Team to define areas of emphasis for new Air Force research programs. A series of mission and crew interface matrices (Table 1) were developed assuming that new aeronautical systems would use known or contemplated technologies available within the next several decades.

The new aerospace systems *technologies*, primarily in electronics, permit better and more nearly real-time target acquisition. This, coupled with more capable communications, computation, and presentation techniques all presage a glut of needed information. The man-information interface is probably the single most important future challenge, since this potential mass of information promises to overwhelm present concepts of decision-making. This problem, plus others noted in the matrices which place new or growing burdens on the crew, suggest that:

1. Biotechnology research programs will be needed to determine the most useful presentation and training techniques to handle more data and higher data rates for real-time decision-making. It seems clear that support of crew members, other than the pilot, must be defined and substantially augmented for many missions.
2. Presentation techniques must be explored so that quick, useful decisions can be made in minimum time. These presentation schemes should not be limited to the cockpit. Command and control centers, whether airborne or on the ground, must include advanced data displays with computer-created alternate responses to enemy actions or system degradation. Massive expansion in the ability to acquire and present information will require new ways to present this information to the aircrew; it will also involve new concepts and research for ground (command) data presentation. Nuclear, radar, I.R. and defense mechanisms of all varieties will increase dependence on unmanned or standoff systems. This will require presentation of battle status, target location and condition, and the identification and location of friendly forces to command control elements. The ability of the presentation to maximize the use of command judgment should be the target of a thorough biotechnology effort.
3. The probable increase in automatic control of airborne systems, even though manned, suggests a subtle new impact on the crew member's physical and mental capabilities. This is the impact of surprise responses of the aircrew's own vehicle. Under automatic control, vehicles can be expected to avoid programmed hazards, to produce changes in mission plan, to respond to external third party commands, and to find enemy targets without warning to the crew which may be on board for specialized reasons (go/no-no nuclear, friend or foe identification, weapon selection, return to base decisions, etc.) The crew must decide whether the automatic maneuver or

Table 1
Aeronautical Systems Mission Profiles
1980—2000

Tactical Systems

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
<u>Offense</u> Deep interdiction	<5 hrs (max. penetration time ≅1.0 hr)	<10,000′	Air-air & grd-to-air weapons, EMP, CW, dirt in air, radiation laser*	Low-alt weather	Self-defense Target acq. Weapon selection	Adequate intelligence & 3rd party direction* Man-info interface*
Battlefield interdiction	<4 hrs	Minimum to 10,000′	Same as above plus guns	Same & CW, laser*, intense G, radiation*	Same plus mobile target acquisition	Same except smaller moving targets
Close air support	<3 hrs (multi-mission)	Same	Same as above	Same as battlefield interdict. plus air dust	Same as in interdict. plus multi-mission fatigue	Same plus friend & foe decision
Counter Air	<5 hrs	Minimum to 60,000′	Air to air, EMP, radiation, laser*	Weather	Self-def. target acq. friend & foe	Potential 3rd party direction & automation*
<u>Defense</u> Counter Air	<3 hrs (multi-mission)	Minimum to 60,000′	Air to air, EMP, radiation, laser*	Weather	Self-def. target acq. friend & foe	Potential 3rd party direction (AWACS-like)* automation*
Air battle direction	12 hrs airborne*	40,000′	Air to air, EMP, radiation, laser*	Weather	Boredom + complex game coordination	Developing mission: performance shown utilizes near term technology
Air mission direction (data link platform)	60 hrs airborne*	30,000′ to 80,000′	Air to air, EMP, radiation, laser*	Advanced fuels	Boredom, physical sustenance	Developing mission: performance shown utilizes 1990-2000 technology
<u>Reconnaissance</u> Normal concept	<5 hrs	<10,000′	Same as interdiction	Same as interdiction	Self-def. target acq.	Potential automation except self-defense*
C³I	<10 hrs	50,000′ to 90,000′	Benign, but radiation possible	Benign	Adverse takeoff/ landing conditions	Source of requirement for chess player: performance shown utilizes 1990-2000 technology

*New or growing impact on crew.

Table 1 (cont'd)
Aeronautical Systems Mission Profiles
1980—2000

Strategic Systems

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
<u>C³I</u> data link platform	60 hrs airborne*	30,000' to 80,000'	Hi priority target Air to air, EMP radiation, laser	Advanced fuels	Boredom, physical sustenance	Performance shown utilizes near term technology
<u>Offense</u> Crew readiness (simulation)	Waiting limit daily-hr's	Simulation	CW/BW base attack nuc. attack, simulation of readiness	Controlled	Complex learning, boredom, motivation	Present problem
Standoff	≅50 hrs: no relief*	1500' to 40,000'	Air to air intercept	Complete silence* or loss of communication Refueling	Indep. hi-responsib.* Self def.* Return base questionable*	Long duration*
Penetration	24 hrs: no relief* (actual penetration ≅2 hours)	0-400' & 60,000' & above, pop-up maneuver semi-orbit	Air to air, ground to air, guns, radiat., laser, Terrain avoidance	Refueling, Complete silence* Rough ride	Same as standoff plus terminal navigation recognition	Roughness & maneuver after long duration*
Ballistic missile launcher	50 hrs: no relief	30,000' to 50,000'	Radiation, EMP	Benign	Same as stand-off	Long duration*
VTOL: ballistic missile launcher	<2 hrs in air, 12 on ground*	0 to 30,000'	Benign EMP & RAD (escape)	Benign	Responsibility, boredom	Potential unusual pilot position.* (Standing for takeoff & land, supine cruise)
<u>Reconnaissance</u>	24 hrs: no relief	Same as penetration	Same plus solo mission	Same as penetration	Same as penetration	Same as penetration
<u>Reconnaissance</u>	Sub-orbit and multi-orbit	>100,000'	Space based laser	Hi-G, long dur. launch & landing	Automated	Same as Space Shuttle

*New or growing impact on crew.

Table 1 (cont'd)
Aeronautical Systems Mission Profiles
1980—2000

Support Systems

Mission Function	Duration	Alt.	Exposure	Environment	Mental Burden	Special Notes
Defense Advanced early warning	≅50 hrs*	30,000' to 70,000'	Mild	Completely silent	Self def.* Hi responsib.* Commands intercept*	Automated intercept* Manned t.o./landing
Intercept readiness	Max. 12 hrs alert	30,000' to 70,000'	Normal intercept	Normal intercept	Normal intercept	Present problem
Tactical airlift	<10 hrs multiple missions	50' to 30,000'	Radiation, laser*, small arms	Heat-dust, CBW,* enemy ground forces	Navigation Rough fields Mult. missions	3rd party direction change
Strategic airlift	>10 hrs	1,000' to 40,000'	Benign-potential interception	Benign, long duration	Duration, loss of comm., hazardous cargo	Communication loss
Rescue	<4 hrs multiple missions	0 to 10,000'	Max tactical	Max tactical	3rd party guidance* or none	Multiple unknown tasks
Training & simulation	Long missions*		Simulation of exposure complex sys. & weapons*	Simulation & realism	Battle dir. simulation (training & update of "chess team")	Stress simulation

*New or growing impact on crew.

change in status is normal or emergency, and must be sufficiently informed to prevent loss of effectiveness.

4. Advancing aeronautical technologies promise to make feasible many useful missions of extreme duration. This capability suggests new crew roles which should be explored to determine the limits of crew performance. These roles include, but are not limited to, the following:

   - ☐ Act as custodian of an automatic airborne system. The new airborne systems could have durations of two to five days serving as satellites for specific tactical or strategic purposes. These platforms would be data-gathering and transmission bases or links in constant communications with, or dedicated to, ground elements. Crew members might only monitor the performance and assure the orderly takeoff and return to base of the vehicle. This system would essentially be a man-monitored, ground-commanded drone. Man's presence in the ultimate application of this concept is to assure that a multiplicity of normal and emergency bases can be used, and that the vehicle is a normal manner aircraft when viewed from the standpoint of routine base support systems. This will avoid the necessity of creating special bases like those demanded for missile or drone launch and retrieval. The man also provides the last stage in the graceful degradation of the system, thus saving the platform for future use.
   - ☐ Supervise the complete command and control of major battle situations from an airborne platform, utilizing the information available from all data-gathering systems, whether on board, on the ground, or in separate aerospace platforms.
   - ☐ Operate the ultimate standoff weapon system where ballistic missiles or defensive weapons are carried in long duration aircraft, some of which are continuously airborne. These systems could have durations measured in days. There are many possible variations of these mission scenarios; but all such concepts demand knowledge of rest cycles, presentation of data to crews whose attention may not be focused, life support for day-night cycles of duty and the limits of human performance when demands for maximum mental performance is interspersed with hours of tedium.

5. Technology will continually increase Vertical Take-off/Landing (VTOL) capability. One alternative basing option for small ballistic weapon systems suggests a VTOL aircraft of modest range initially based on protected bases. On notification, the aircraft with one small missile deploys to a previously located, but secret, destination about 250 miles away. The missile is protected by random selection of these peripheral bases, and can be launched on command or returned to the home base. The aircrew can be on alert to accelerate the initial departure. Takeoff attitude can be standing, whereas flyout position can be prone. The wait at the remote missile launch site could be long, and the minimum crew can have go/no-go responsibility in the event of no command received. The physical requirements are unusual but not severe, the cockpit attitude is substantially different, and inactive time on station will probably be long. The decision to move to an alternate, pre-planned site may be made by the crew alone. This unique mission should be explored for biotechnology research demands.

6. All such mission concepts imply special burdens on learning and training. The specialization of the crew members, the automation of much of the mission, and the inevitable revolution in the display process, all impose new tasks for the developers of partial and total mission simulators. The simulation process and equipment may be as essential to success as the mission equipment itself.

7. Stealth techniques that impart low observability to aeronautical systems flying in the earth's atmosphere may become an integral aspect of systems design in the immediate future. Low observability will be manifested in a reduced total aeronautical system signature. Reducing the aero vehicle's detectibility by reducing the optical, electro, acoustic, and infrared signatures beyond the capabilities of known or anticipated detection devices, will place additional mental and physiological demands on the aeronautical warrior of the future. The management of designed-in and on-board stealth supporting subsystems will demand greater sensory perception than in today's modern stability augmented aircraft. In tomorrow's cockpit, there will be little dependence on kinesthetic, seat of the pants, cues for a significant part of the mission profile, primarily during attack or target rendezvous. However, there will be normal demands on the pilot's human perceptions during takeoff, landing and low altitude terrain avoidance.
8. Crew personnel in future combat operations may be exposed to the following kinds of radiation in increasing quantities:

- ☐ Residual and acute ionizing radiation from conventional nuclear or neutron weapons. Duration of the hazard exposure can be from a few hours to up to two or three days. Crews must also be able to return to bases that contain radioactive fallout.

- ☐ Pulsed, high and medium threats from both ground and air-based lasers. The effect of radiation/flash blindness and disruption of optical devices on crew vision requires consideration.

- ☐ Other electromagnetic radiation threats are possible—electro-magnetic pulse (EMP) nuclear weapons that can seriously disrupt the operation of electronics equipment. Microwave weapons are not likely, partly because of the limitations due to the atmosphere and partly because other threats—ionizing radiation, lasers and EMP—appear to be more cost effective. Aircrew hazard limits must be determined, however, if exposed to microwaves flying over enemy radar or bathed with energy emitted from on-board equipment.

2

Human-Machine Symbiosis with Extraordinarily Complex Systems

Projections of future aeronautical systems exhibit a common trend toward more complexity of machines, with a concomitant shift in human roles toward monitoring, situation synthesis, supervision, and decision-making. Increased automation with more reliance on computers and automatic control has been adopted as the basis for the solution of many existing and anticipated problems. While more automation does sometimes promise salvation, this is a mixed blessing. Almost all tasks that can be defined in sufficient detail can be automated, but the result can be so costly, complex and inflexible that they become self-defeating. What is good, or even essential, for the human may be inconvenient or inefficient for the machine. Allocations of roles between humans and machines and questions of cost and effectiveness are crucial. For symbiotic automation to be effective many improvements are required in all aspects of the interactions between the human and automation elements of aeronautical systems.

Platform Commander Decision Making

Automation will be ubiquitous in Air Force systems by the year 2000. Since the C^3I center is the point at which the fruits of automation enter and from which decisions originate, the problems and needs of symbiotic automation of the command platform deserve first consideration.

Decision Making

The basic task of the commander of a semi-automated platform is that of decision-making. Research is needed to assist the intellectual task of decision-making while still maintaining the platform's operation. Improvements are needed in the technology for derivation of options which embody the complex value systems associated with command decisions and their relationship to higher command. Studies are needed of decision-making during the uncertainty associated with apocalyptic situations. Also needed are evaluations of decision-making impairments caused by stress and formulation of mechanisms for alleviating them. Thought must also be given to improving the effectiveness of distributed decision-making.

User Confidence

Users must have appropriate confidence in the functioning of their automated systems. Under-confidence leads to under utilization, but overconfidence can have more unforgiving consequences. Research is needed to explore and verify techniques to measure and assess models of user-machine operation. These models should provide estimates of user confidence, reliability, and familiarity.

Understanding and Coping with System Changes

The key to good systems design is flexibility rather than an attempt to write perfect system specifications. A formal structure is needed for understanding, describing and managing human-machine system modifications and why modification is needed and the specification of the nature of the modifications. It should further

provide for describing and integrating related aspects of the modification (hardware, software, training, etc.).

System Tailoring

Automation systems can be made more effective if methods are incorporated into their design for adapting to the individual differences of human operators. For this, research is needed to identify ways of determining individual decision-making styles. This will include determining the information processing characteristics as well as appropriate system function allocations between machine and man. An initial effort is required to determine the critical parameters relating to individual differences in terms of cognitive style, decision-making style, information processing style, and system function which are amenable to individual characterizations.

Multiple Operators

Research is also needed in optimizing complex systems which involve many operators. The roles that human and machine components will be required to perform and their allocations require definition. Improvements and training in crisis management are needed, as are ways for cooperative, distributed decision aiding. Rules are needed for decision load sharing between humans and machines and for unburdening both man and machines. Channels of communication between operators and machines must exist, but restrictions are needed to maintain appropriate workloads. Additional advances are needed in existing techniques for describing human-machine systems and for rule-based systems.

Automation in Voice Communications

Improving the receipt and cognitive handling of auditory information should be explored. Because of limitations of existing approaches and expected increases in information densities, vigorous research is needed in communication management of multiple sources and the automated systems to improve auditory efficiency. Development of visual displays integrated with speech recognition control of the display could also provide significant increase in operator efficiency. Also needed are communication translators to optimize interoperability of strategic and tactical forces by minimizing confused or misrepresented meanings of messages, all of which, in an airborne system, must contend with ambient noise and speech interference.

System Modeling and Assessment

A large number of engineering models of human behavior when working in concert with machines have been developed, but they are not adequate to assess many current man-machine systems. They fall far short of those models that will be required for development and evaluation of future automated systems. Research is needed to extend current man-machine modeling research to create models of the symbiotic man-machine system from which predictions of system performance and reliability can be made under conditions in which neither, either, or both symbiotic companions are impaired due to such causes as hostile enemy action, adverse environments, excess workloads, fatigue, machine, or communication failures, etc. The models should particularly stress the prediction and understanding of human error so that design, pilot or operator selection, doctrine and training can all contribute to the diminution of human error and to the increase of systems reliability. These models should have the capability to have the man assume different roles in the weapons systems as he or the machine become impaired. Associated with this is a need for models of human impairment that can describe the deterioration of judgment and which can be used to determine how these impairments can be prevented, delayed, or compensated for.

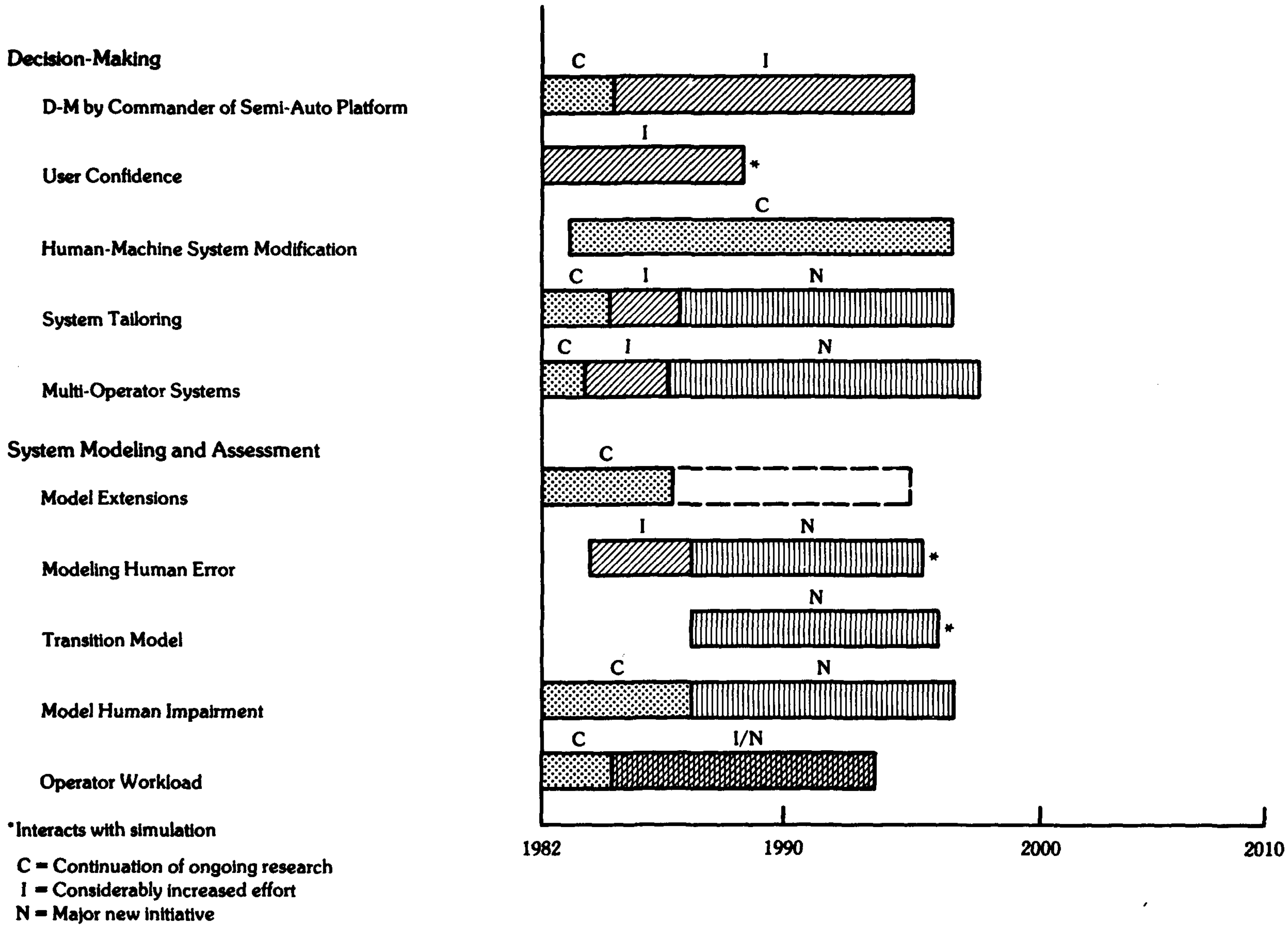


Figure 1
Human-Machine Symbiosis - Future Trends

3

Human Machine Information Interfaces

The previous chapter addressed the overall issues if the human-machine symbiosis with highly automated systems from a perspective which focused on the desirable properties of such systems and the descriptive models needed for assessments and role assignments. This chapter is a companion which emphasizes the more parochial "ins and outs" — the interface issues. Because both chapters deal with similar issues from a different perspective, some duplication in the discussions is inherent and even desirable.

A functional model of an information interface for advanced automation must consider the representation of the real world to the aircrewman and the effect of that representation. An effective interface requires a performance-oriented understanding of the types of information involved and the roles of humans and machines. Situational information available to the human is an active integration of background data and real-time event data. In C^3I battle management missions, background and real-time information have situational and process features which are becoming more dense and complex. The role of the pilot will continue to evolve in the direction of a system or process monitor/supervisor and decision-maker.

Relevant Issues

The research approaches for enhancing the information interface in future, highly automated systems must consider the increasing demand on battle managers, pilots and crew members who perform in an information intensive environment. Consequently, several key issues germane to the current roles of the human require careful consideration and, in some cases, reevaluation. These issues include:

- ☐ Use of natural abilities and psycho-physiological functions needed to produce a compatible user/system interface.
- ☐ Expanded emphasis on the development of embedded training techniques that include idiosyncratic effects associated with both man and machine.
- ☐ Techniques for increasing accuracy while reducing response time in cognitive task structures.
- ☐ Better treatment of uncertainty and complex forms associated with the engagement, the human perception of the engagement.
- ☐ Performance tradeoffs in interface design and system interaction based on individual differences, e.g., dialogue and information transferral, decision styles.
- ☐ Approaches to flexible growth systems that offer real time modification based on changing missions and evolutionary enhancement of overall system capability. The approaches must necessarily address levels of human proficiency and needs in both of these circumstances.

Enabling Technologies

Particular emphasis is placed on those biotechnological research issues which either offer potential for enhancing the human as controller, information processor, and decision maker or improving the human role in light of extrapolating

observed problems in the context of current systems. It is a necessary planning constraint that those technologies which offer the most gain in enabling improvement or enhancement must be considered. Six major enabling technology categories (displays, control and input, non-invasive physiological measuring devices, information systems, communications, and avionics) require research and development to meet the biotechnological needs of the next century.

Sensory-Motor Integration

For the aircrewman to benefit from these technologies, significant strides in sensory motor research must be achieved by the year 2000. Sensory motor research in the past studied the sensory and motor systems separately and, indeed, each of the sensory systems was considered individually. Future research, however, must integrate all of the senses with the motor system to determine how all are used to update the human's model of the environment. Basic sensory-motor research should incorporate artificial intelligence with neuroscience and cognitive science to provide better models of interacting subsystems.

This should lead to the determination and quantification of the innate and learned sensory-motor transfer functions in humans by defining sensory-motor transformations and parallel processing. This will require study of the information capacity of single receptors, the information capacity of sets of receptors, and the use of multisensory inputs to enhance reliability and speed of response. Studies must also be made of multisensory coordination and conflict when multiple sensory inputs are used and the motor planning needed to act on these multisensory inputs.

Interface Language

To enhance and speed communication via the senses, symbolic interface languages are needed to minimize interpretation effort and learning difficulty. Mimetic systems which use topographic representation of geographic space and iconics using symbolic features offer opportunities for productive research.

Research in natural language interfaces (those which use conversational messages rather than symbols or meter displays) should also be pursued to develop intelligent interface agents that can act as intermediaries between the user and the system. Natural language can play a vital role in providing compact descriptions of complex conditions by natural language processing. This process would translate natural language to and from a computer and expert systems to allow access of data bases via dialog rather than explicit query. Current trends in natural language parsing suggest that future generations of automated systems will be able to have dialog entries for relational processing and unparsing inferences from knowledge data bases for operator use.

Research is needed to develop the use of spoken or written output to highlight salient aspects or signal situational changes in complex visual or multimodal displays. This work should study human cognition to determine what aspects of a visual display are most salient.

Needed also are ways for monitoring short term factors, e.g., current physiological state or direction of gaze, to configure expert systems that can update users models and learn from experience. These systems would acquire pertinent data on each mission and integrate this into a general user model to allow restructuring of its communication display, either linguistically or visually, to the individual pilot's needs.

Display Media

The technology needed to provide a wide field-of-view display medium should be the object of research between now and 2000. This display medium needs to be able to display information from various sources to the visual sense of the operator. Biotechnology research must be associated with this technological research and must address the issues of display configuration and spatio-temporal interaction of display images with the operator's visual senses.

Technological advances are also expected to provide unique tactile and auditory displays by 2000. Research will be needed to develop methods for coding information using these sensory modalities. The greatest advances in man-machine information transfer will occur when these nonvisual displays are combined with visual displays. Research is needed with these multimodal displays

to assess response time, accuracy, and content transfer to the operator during both vigilance and high workload tasks.

Operator Input

To provide communications from the man to the system, research will be needed in operator control and information input to the system. Conventional controls have been limited to hand and foot motions used for tracking or for discrete switching. These manipulators and their associated signal conditioning and shaping still require significant improvements as subsystems of fly-by-wire or fly-by-light flight control and guidance systems.

In the area of nonconventional control and input, voice input is the object of much research in other man-computer interfaces. Special work is needed, however, to determine its proper share of the input load in the present environment. More fundamental work is needed in control by the detection of eye and other body movements, sensing muscle group contractions using EMG signals, and the direct tapping of brain signals. The use of the EMG or event related potentials in conjunction with adaptive controllers, especially, may provide more viable control elements for high performance platforms. Major robotics developments in multimodal input and control are required in dog-fight control especially when multiple weapons systems are also used. Automation of these functions must be integrated with research on high level supervisory contact by on-board crew and remote piloting from ground stations of distant, airborne command platforms. Automation will also be needed for refueling and weapons loading in high radiation or CW environments that might impair or remove ground crews yet might not penetrate cockpit defense systems.

These applications of robotic systems will require the development of new tactile sensors and data processing algorithms. The specific areas of needed research should be in the use of static and dynamic vision, static and dynamic tactile sensation, and the interaction of multimodal sensory data.

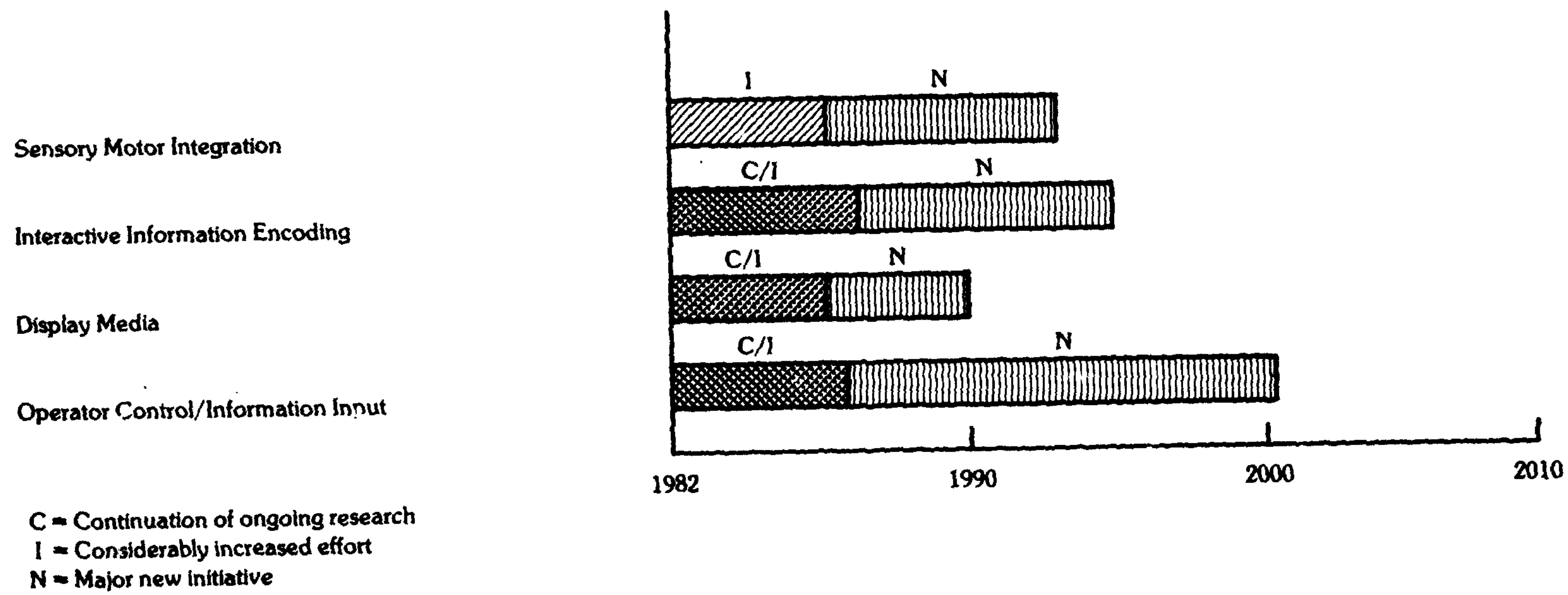


Figure 2
Human-Machine Information Interface - Future Trends

4

High Intensity, Unforgiving Missions—Mission Stress, Protection and Performance Enhancement

This chapter analyzes the new mission requirements and stresses anticipated in aeronautical systems and addresses the problems of operator effectiveness and degradation, and potential means of increasing mission effectiveness, and safety and crew biodynamic protection. Primary new factors foreseen are long duration missions (over 60 hours), severe six degree of motion exposure in low-level, high-speed mission phases and variable duration missions at altitudes in excess of 100,000′ (30,480 m).

The chapter discusses research requirements in two major areas: performance and protection. Although these areas, and particularly the subareas analyzed, overlap to some extent they are all included for completeness.

Clinical Monitoring and Enhancement of Aircrew Performance

By the year 2000, new missions will add stress associated with extremely long duration flights as well as clinical, biological, electromagnetic and nuclear environments. For this reason, measurements must be developed that accurately and reliably predict performance degradation and that are noninvasive and noninterfering; research must be conducted to determine the interrelationships of these measures and criteria developed for acceptable deviation of the measures; and, finally, computer algorithms developed to make decisions based upon the measurements. It is probable that no single parameter will provide a reliable index of degradation in aircrew performance. Furthermore, because of the widely different performance tolerance envelopes, it is probable that a performance profile on each individual will be needed. This profile may be contained on a personal characteristic card carried by each crewman and which is plugged into the aircraft computer before takeoff.

In order to meet this need, research must be conducted to devise methods of monitoring physiological and psychological parameters that index the status of the operator and alert the aircrew or ground control personnel of impending performance degradation so that appropriate corrective action can be taken.

Future efforts must be directed toward finding new measurements which are less invasive and more sensitive than those presently available. An example of such an innovative technique is the magnetoencephalogram which provides non-contact monitoring of brain activity. Another potentially useful technique might be to monitor the crewman's information processing strategies; these may change as workload stress and fatigue increase. Maladaptive changes in perceptual filtering, attention focusing, and criteria adjustment adopted by the stressed operator could serve as suitable performance measures.

Because single work load and stress measures do not yield definitive indications of reaching maximum tolerance or operator capability, the use of multiparameter decision theory and pattern recognition methods may be required in handling the important performance measures. These methods can combine many measures to produce a single value on a "stress" or "work load" scale for which a maximum tolerance for a mission can be determined.

Other efforts should then be directed towards developing the appropriate computer control algorithms to make decisions based on the monitored parameters. The application of artificial intelligence theory and methods will be of importance in this final phase.

This research has three levels of specific potential applications.

- ☐ Cueing the aircrewman or commander that he has reached his threshold and that continuing will jeopardize the mission.
- ☐ Off-line adaptation of personal performance by periodic testing for updating personal performance profiles, retraining, or reassignment.
- ☐ Biocybernetic adaptation of the aircraft control and display functions to alter their characteristics to partially match the operator's performance capability.

Predictive Modeling of Aircrew Performance

Predictive modeling is useful for determining the degree to which new tactics or equipment can resolve performance problems. Modeling of human capacity for physical work is well advanced as are predictions of thermal comfort, performance decrements and tolerance limits for acute (1-2 hour) and extended (2-12 hours) workload effects. Models are available for acceleration, for some drug effects, hypoxia, and other stressors. Such models are extremely useful in identifying problems, in assessing solutions, in minimizing test and evaluation costs, and in reducing risks of human testing.

Future studies to meet the needs of the year 2000 should concentrate on integrating the individual models to include the interactive effects of drugs, acceleration, thermal factors, pressure, vibration, circadian rhythms, nutrition, dehydration, sleep loss, etc. Those efforts will require validation of the interactive model.

Prevention of Motion Sickness

Motion sickness in flight is not a new problem in military aviation and much is known of the etiology of the condition. However, it is still a significant cause of performance impairment. This problem is apt to become more severe in the projected mission scenarios that expose the aircrew to motions and tasks that are even more stressful.

Since there is a wide variation in individual susceptibility, it is important that the aircrew selection process include the prediction of an individual's ability to develop and retain protective adaptation during training. This requires the development of a procedure which reliably excludes those individuals who will not develop adequate protective adaptation to provocative motion.

Although improved selection will identify the least susceptible trainees, drugs and therapeutic procedures may still be needed for crewmen to tolerate the most severe scenarios. Research is needed to develop new drugs and therapeutic procedures to meet this requirement. Studies should be directed at developing a better understanding of the underlying neurophysiological processes of motion sickness, the effectiveness and duration of the new drugs, and the mechanism of the drug's action.

Finally, research into the influence of cockpit design on motion sickness is needed. This research should be directed toward establishing design criteria that will minimize the visual and whole body motion stimuli that precipitate motion sickness.

Prevention of Spatial Disorientation

Despite continuing efforts to educate pilots about the mechanisms and hazards of spatial disorientation in flight as well as changes in instrumentation and modifications to flight procedures, the Air Force continues to lose valuable aircrew and aircraft in mishaps caused by spatial disorientation. A better understanding of the mechanisms of spatial disorientation susceptibility is needed so that spatial orientation is maintained under all flight conditions. The goal of this research should be to improve understanding of the pathogenesis of disorientation through psychophysical and control behavior measures obtained from neurophysiological investigations. These investigations should include classical studies to identify stimuli that produce orientational illness; but they should also concentrate on identifying conditions or factors that produce degradation of control responses through perceptive, cognitive or motor deterioration. Studies of orientation

information processing that emphasize information prioritizing mechanisms and orientation decision strategies will aid in understanding the behavior and manifestations of spatial disorientation that contribute to mishaps.

Performance Augmentation in High Speed, Low Level Flight

The expansion of aircraft capability into advanced forms of low altitude, high speed, terrain avoidance, along with six-degree of freedom aircraft maneuverability, presents new control and restraint problems for the designer and pilot. The definitions and solutions of the problem can only be identified through rational restructuring of the stresses and dynamics of the situation. This requires that combined models be developed for the aircraft and for the pilot. Studies in this problem area must provide the background information needed to obtain the optimal performance of the man/aircraft system.

The research should result in provision of controllers and control methods for combinations of manual, voice, pedal, neuromuscular, or neuro-myoelectric systems that will passively or actively input pilot control intent without equivocation. Further, performance sharing and enhancement through model-directed, artificial intelligence/biocybernetic systems in a pilot/vehicle symbiosis should be a further goal of the research. Integration of the pilot and vehicle to provide performance sharing requires the extension of artificial intelligence, pattern recognition, distributed problem solving, sensory processing (both human and machine) and hierarchial control methodologies. Under severe stress conditions, pilot performance changes must be evaluated to provide for automatic task partitioning with onboard intelligent equipment. These research efforts must be integrated with the work on the human information interface discussed in Chapter 3.

Exploration of Unconventional Man/Machine Interface

As further discussed in Chapter 3, projected mission requirements place great demands upon the information processing capacity of the weapon systems operator. His performance can be enhanced by unconventional information transfer. Information saturation of specific sensory and motor channels, in some circumstances, can be avoided by using parallel, rather than serial, information transfer.

The afferent and efferent information handling capacity of the human operator can be improved by developing alternative modes of information transfer. Presently, nearly all input information is processed visually. Research should be conducted to determine if selected information, such as orientation information, can be inputted through the peripheral visual fields.

Studies to translate aircraft and weapons motion and position parameters into acoustic or vibrotactile information should also be pursued. The possibility of direct neural stimulation, either through peripheral nerve skin electrodes or of the central nervous system by complex neuroelectric induction systems (such as electromagnetic transmission), must also be considered. Preprocessing of required sensory information to form optimal coding strategies for each channel will be necessary regardless of the input modes used.

Perhaps more practical is the prospect of coupling biologically generated information with the system monitoring the operator's status or for translating his desires and intentions into effect. The most promising of these mechanisms are the myoelectric, myomechanical, and neuroelectric effectors.

Enhancement of Communication

Voice activated controls are technically feasible as a potential means of assisting the aircrew. Development and incorporation of these devices into a reliable control system and into the inflight communications system will require an expanded knowledge of speech words, speech recognition, and speaker identification as described in Chapter 3.

Definition and Modeling of Multiple Stress Effects

Three fundamental objectives must be met to solve the problems imposed by the multiple stress environment anticipated in future aircraft systems. First, the stressors encountered should be delineated, classified, analyzed, and studied empirically. Second, data derived from

experimental studies should be incorporated into theoretical models that account for linear and non-linear interactive effects. Finally, the theoretical models should be validated under operational conditions or full scale simulations. The overall objective for these efforts would be to achieve a full and comprehensive understanding of the effects of multiple stressors on human functioning in the flight environment. Ultimately, this knowledge could be employed to develop optimal countermeasures against the multiple stressors encountered in flight.

The intrinsic and extrinsic stressors must be anticipated for all possible scenarios. The variables influencing the psychological and physiological substrate of the aircrew should be delineated and a method for combining the stressors should be established.

Empirical studies, investigating specific, high probability and operationally realistic combinations of the above parameters can then be conducted. The results of these studies should be incorporated into large scale system models derived from complex system theory. These models can be explored by use of techniques such as binary intent matrices, binary weighting systems, and linear system theory.

Protection
Enhancement of Tolerance for Multistress Environments

Humans vary in ability to tolerate physical, physiological, and psychological stress. Tolerance to stress can generally be increased in most individuals through acclimatization of repeated exposure. Research is needed in developing and evaluating techniques for induction and maintenance of acclimatization to the physical, physiological, and psychological stresses of aircrew missions. The possibilities of drug enhancement and the potential problem of interaction of procedures and "cross acclimatization" must also be examined.

High G Protection for Tactical Missions

The year 2000 may see the need for $+G_z$ protective garments that will protect a pilot to 12 $+G_z$. In addition, the expected mission scenarios will require that repeated exposure to high G levels will be a significant physical and physiological stressor. Research is needed to develop and test protective devices that will allow the pilot to engage enemy aircraft under high G conditions. These devices must not have a significant effect on either his ability to adequately perform tasks or adversely affect his basic physiological defense mechanisms. This may require integration of physiological protection such as positive pressure breathing, infrasound techniques to improve pulmonary ventilation, CO_2 pre-breathing, use of pharmacologic agents and M-1/L-1 straining maneuvers. Mechanical protection must also be provided, e.g., ECG triggered pulsatile counterpressure, upgraded anti-G valves, high acceleration cockpit with tilt back seat, and risk maneuvering sequences, for obtaining optimum G tolerance with minimal pilot performance distraction or degradation.

Finally, screening of trainees for G tolerance should be established. This will require the development of tests and criteria for identification of individuals with super high $+G_z$ tolerance.

Innovative Head Interacting Devices

Conventional helmet design techniques cannot meet the needs of the future. A systems analysis is needed to identify and evaluate the required functions of head devices for each mission. These studies should also identify new technologies for performing each head-interacting function and integrate them into nonencumbering equipment. Special emphasis should be given to interfacing head devices with the aircraft and for providing active components that deploy only when needed. Iterative prototyping will be needed to assure practical integrated function.

Integration of Protective Clothing Ensembles

Industry is now able to produce fibers to meet almost any specification of size, weight, bulk density, durability, compression regain, wickability, tactility, etc. New weaves, e.g., triaxial, fabrics, e.g., microporous, and materials, e.g., armor, films, are also becoming available. Functional clothing design is rapidly replacing conventional tailoring for mountaineering and extreme cold weather clothing. New handwear, headwear, restraints, and body supports are becoming available.

Advantage should be taken of these new materials and active modes of protection for devising combinations of protective functions into ensembles that are wearable, fully functional and minimally encumbering. These advanced garments should combine protection from extreme thermal environments, non-ionizing radiation, dynamic forces, altitude and NBC threats.

Assisted Escape Initiation

As aircraft performance has increased, out-of-envelope ejections during man-controlled flight have increased as have the fatality rates to an average of 25% over the last five years. An escape system capable of covering the entire operating envelope of future aircraft is needed. This system should include oriented escape initiation using automatic systems for alerting, warning and, in extreme cases, providing actual escape initiation. Cost tradeoffs can be applied to the definition of appropriate levels of effort devoted to assisted initiation and expanded envelopes. Special consideration will also be needed for emergency escape from long duration mission aircraft in which some of the crew will be sleeping, eating or moving about.

Extended Escape Envelopes

In addition to providing adequate escape systems that can separate the man from the aircraft, the escape envelope should also be increased. The primary limitations on the escape envelope are aircraft speed and altitude, and to widen the envelope will require significant departures from current ejection system techniques.

Three major problem areas in the escape sequence should be addressed.

- ☐ Separation from an airframe which may be accelerating
- ☐ Controlled deceleration by providing protection from wind blast
- ☐ Deployment and operation of a descent system prior to ground contact while providing environmental protection as appropriate.

Occupant Crash Protection

In those mishaps where the aircraft is not equipped with escape systems, e.g., helicopters, or the escape system cannot be activated, the aircrew must be protected by their restraints, the seat, and/or the airframe itself. Although many studies have been conducted in crash protection of aircraft and ground vehicles, significant research is still needed to determine aircrew crash tolerances, load mediation techniques, and optimized restraint systems design. Design criteria for cockpit protuberances and padding are also needed to reduce injury and death due to body contact with cockpit surfaces.

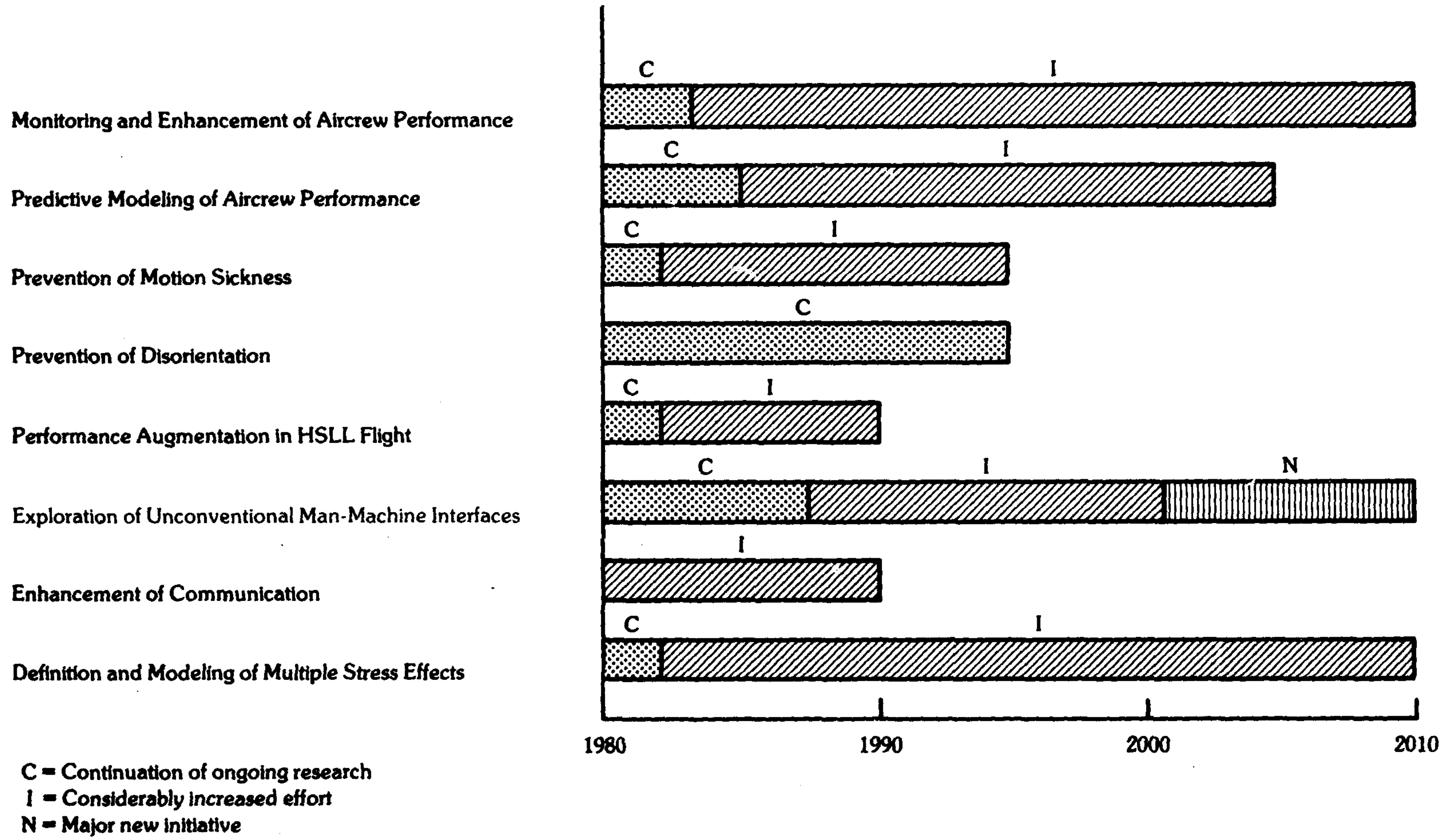


Figure 3
High Intensity, Unforgiving Missions - Performance

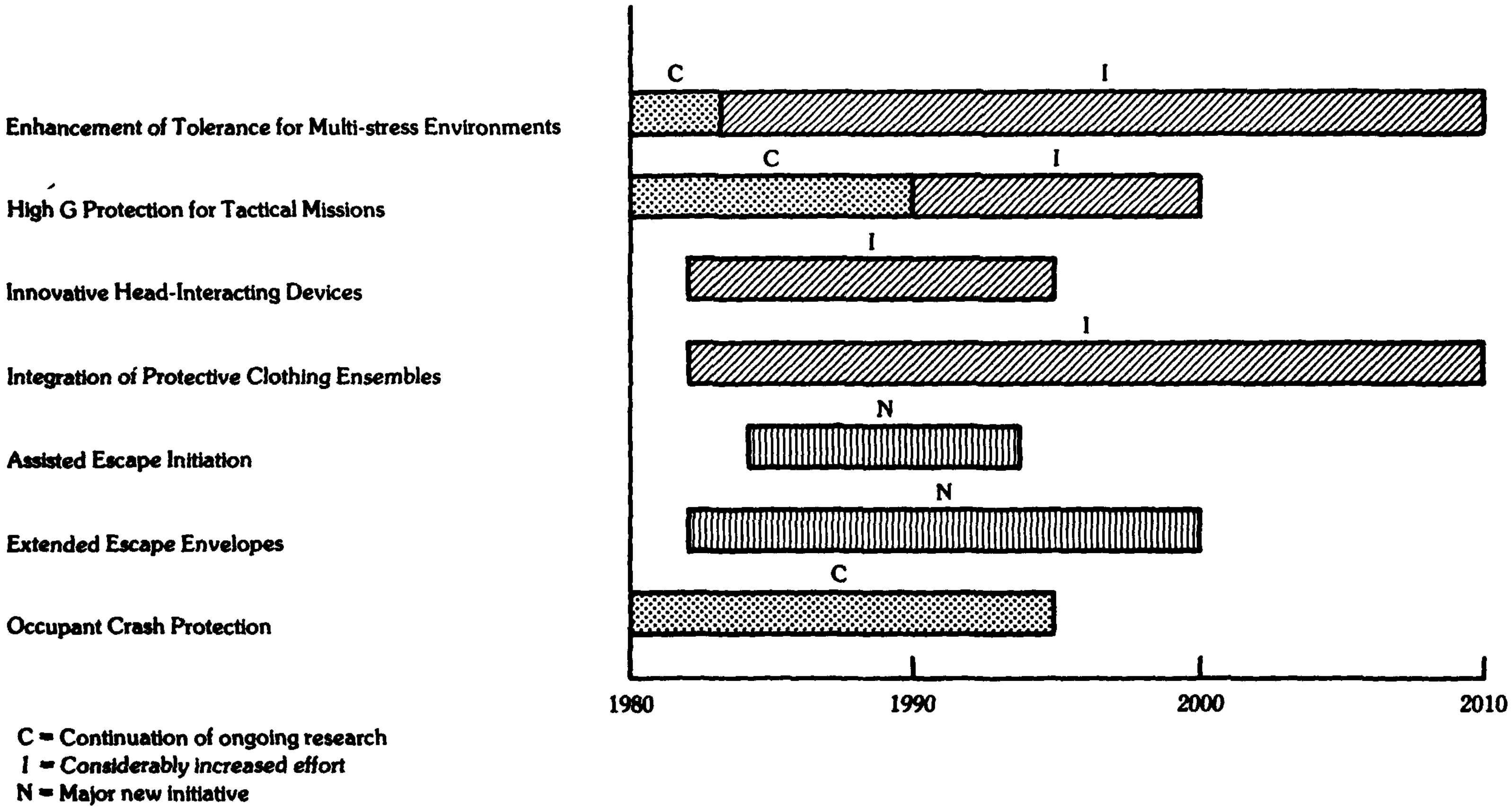


Figure 4
High Intensity, Unforgiving Missions - Protection

5

Simulation

In 1980, military flight simulators are accepted equipment for: (1) development and maintenance of skills for operational flight crews; (2) engineering design and development; and (3) research. Their use transcends initial, recurrent and transitional flight training for each USAF flight task. Their use can only be broadened, their application spread and their importance increased. The expansion of use of simulation is driven by the need to maintain a high level of combat proficiency and, *at the same time*, conserve fuel, equipment, and crew lives.

Research is required not only to improve simulator design and performance and to retrofit older simulators, but, most importantly to improve cost and training effectiveness. These latter goals will not necessarily be reached by adherence to the concept that all improvements must accrue from increased realism and complexity of equipment.

The areas in which research are needed are:

- ☐ Basic data on spatial orientation and visual perception.
- ☐ Simulation as a tool for system designs involving operator-automation-information presentation interfaces.
- ☐ Operator performance enhancement through simulator research.

Simulation and Flight Training

Needed is basic research on the interactions among spatial orientation, perception and perceptual motor learning. A characteristic of this interaction is plasticity, or the adaptability to gradually rearrange inputs and responses to subserve spatial orientation. Sudden alterations of input patterns, in contrast, may lead to spatial disorientation or motion sickness. At present, our knowledge of intersensory plasticity is limited and basic information would be most helpful in the design of simulators and their use in perceptual-motor training. The existing visual perceptual literature is concerned with static observers and the correlation of these data with that for the moving observer is low or zero.

Therefore the need is for research on the gaze stability mechanisms, including the influence of common degrading factors such as stress, vibration, aging, etc., on gaze stability. This research should further define the interaction of visual, vestibular and somesthetic cues on human perception of spatial orientation when the observer is moving through space. Increased emphasis is needed on behavior and perception in contrast to the emphasis of the last decade, i.e., a focus on physiological and clinical aspects.

To facilitate further research on orientation perception, an effort should be made to develop and validate improved methods for measurement of spatial orientation, including both perceptual and performance measures. Needed also is research to establish "how much motion is enough" in practical flight simulators. Alternative schemes for motion "washout" should be evaluated, including the utility of "full gain" external disturbance cueing and "reduced gain" active maneuver cueing. Tradeoffs between motion base excursion and cockpit interior somesthetic cueing should also be evaluated.

Analytical Design Requirements

Current simulation requirements are obtained through a combination of experiments and known equipment capabilities and limitations. For the complex demands of the 2000's, this approach is too inefficient and costly. By that period, a systematic method must, and can be developed based on human operator performance models and mission requirements.

As a first step, human operator perception, control, and decision theories, combined with quantitative descriptions of the specific tasks and needed data handling burden can be combined to establish fidelity requirements for simulation of visual and motion systems. The research required will also include validation of the theoretical models. Experimental data needed to define and validate the models must be obtained and will require a high fidelity, ground based simulation.

Measurement of human performance during simulator evaluation is an area requiring research during the next twenty years. Measures are needed that quantify those aspects of man-machine performance that the pilot is or should be observing and controlling. These should be incorporated into a model-based methodology suitable for suggesting optional performance strategies and metrics for future USAF missions. The sensitivity and validity of these potential measures must be evaluated in simulated and actual flight to determine their utility.

Research is needed in the validation of ground based simulators to provide the basic experimental data rquired for future, complex man-machine system designs and training. This work should define the required validation data and experiments and reduce the results into a proven source of "can and cannot do"experience with ground based simulators. The greatest immediate need is in the tactical area of night/all weather ground attack.

Visual Scene Augmentation in Flight Training Simulators

Flight training simulators have been mainly regarded as aircraft substitutes both in terms of their design and their instructional use. A more enlightened view of flight training simulators is to regard them as devices to facilitate learning skills. Development of augmentation techniques of training, which deliberately depart from realism, appears to be an effective method for increasing simulator effectiveness.

Research is needed to discover principles for the application of visual augmentation (providing more realistic visual displays of the environment outside) to increase the effectiveness of flight training simulators. These studies must determine what kinds of augmentation are most useful and the strategies necessary to use augmentation most effectively.

Fundamental questions about the efficacy of strategies for use of augmentation will require research to answer. These questions include: Should augmentation provide feedback as to the quality of performance? Should augmentation be presented continuously or withdrawn by fixed or adaptive schedule? Are non-conventional displays such as an out of-the-cockpit "birds eye" view of a maneuver, as it is executed, a means of facilitating initial stages of learning?

Simulator Training Process Analysis

Analysis of the simulator training process is needed to prepare for the design of simulation and training programs of the future. The research should develop procedures and guides for the conduct of training process analysis that specify the mechanisms for development of the skills involved in criterion performance.

The methods employed in this research would be analytical and developmental, with multiple interactions, trials and revisions. The benefits would include revised and tested procedures applicable to all USAF future simulators and simulator training program developments.

Two special areas of research are delineated by the current limitations of simulator visual displays. These are the visual tasks associated with target acquisition and low level, low and high speed flight. Research has the objective of increasing the content and resolution of flight simulator displays to approximate more nearly the resolving power of the foveal visual system. Increasing simulator visual display information and resolution would be applicable to the training of individuals involved in tactical target acquisition tasks, rescue and resupply missions, with fixed and rotary wing aircraft.

Simulation and Flight Training

Basic Research on the Interactions Among Spatial Orientation, Perception and Perceptual Motor Learning

Gaze Stability

Analytical Design Requirements for Flight Simulation

Human Operator Performance

Performance Measurement

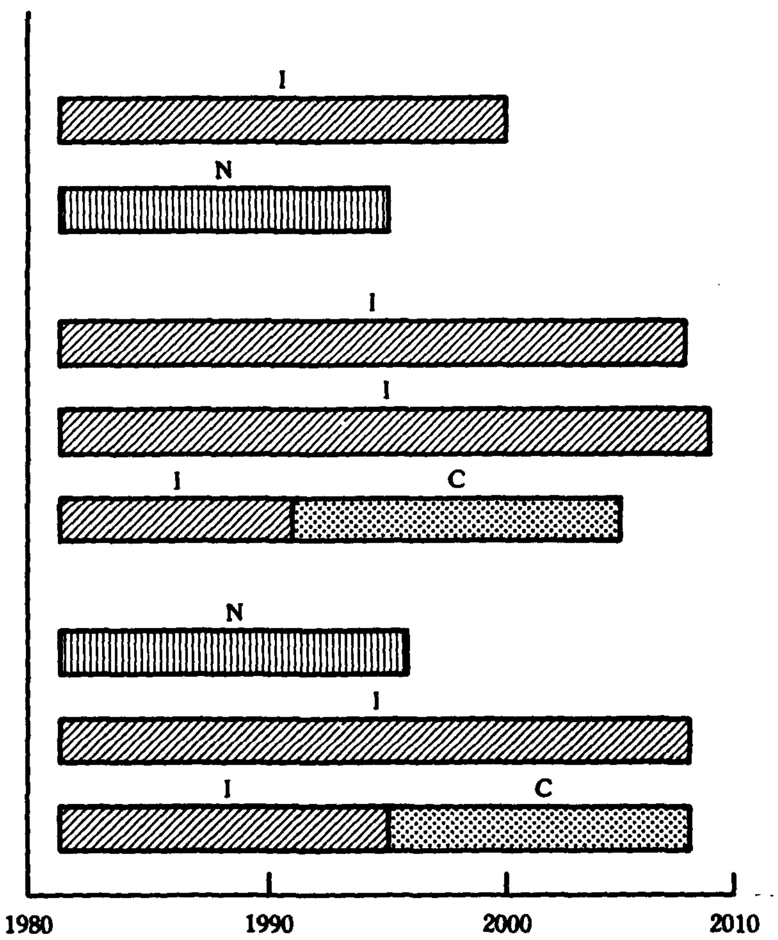
Ground Based Simulation Validation

Visual Scene Augmentation in Flight Training Simulators

Augmentation

Simulator Training Process Analysis

Foveal Image Detection in Simulator Visual Displays



C = Continuation of ongoing research
I = Considerably increased effort
N = Major new initiative

Figure 5
Simulation

6

Crew Selection and Enhancement

Current USAF techniques for selection of pilots are based on traditional psychological tests, psychomotor performance tests, physical standards arising from conventional examination techniques and a semistructured interview to determine motivation. All are applied to a volunteer population. Graduation from college is used as a performance standard.

This process yields a pool of flight training selectees, of whom some 20 percent will not complete flight training. Thus, flight training itself is a selection process, albeit lengthy and rather expensive. (The USAF has about $15,000 invested in a student pilot who washes out at the point of first solo flight.) The trend toward fewer and more complex aircraft makes it desirable to be more selective in identifying superior flying potential in applicants.

Since mission roles will become more and more complex and diverse, the "universally" assignable aircrew member will no longer be possible. While there will be a "minimum set" of standards required for military service, special selection standards will be required for each major aircrew mission role such as tanker, transport, bomber, fighter, RPV controller, weapon systems operators, information processors, etc. Selection standards and training will be closely coupled to mission demands. While there will be a shift in emphasis on the type of mission roles required (from physical/mechanical to information assimilation, integration, decision making, and execution), a wide range of mission roles (including the traditional aircrew roles presently used) will still be needed by 2000.

Selection Criteria Development

The first criterion of selection is that candidates be capable of the physical performance demands of flying. Research is needed to develop instrumentation for monitoring the physiological performance variables in simulators and in flight. Similarly, instrumentation must be developed that can accurately simulate the physical requirements of the crew members under various mission conditions. Further research will be required to establish performance criteria and standards, based on these measures, for each of the crew positions of operational aircraft. Much of the data for these efforts should be obtained during actual flight and should include muscular strength, work, power, endurance, and sustained analytic mental capacity required to perform the various missions' tasks. A laboratory flight simulator will also serve for acquiring data for this purpose.

The motivation of volunteers for flight training requires evaluation to ensure that their motivation is not flawed or misdirected. At present, only the most superficial screening is performed, and there is no feedback to interviewers to allow them to determine if they are picking "winners". Research studies are required of successful and unsuccessful students, highly rated pilots and those who develop a fear of flying to identify the psychogenic features of motivation to fly. These studies should define developmental and historical markers of success that can be used by less skilled evaluators.

The tolerance of a candidate to circadian disturbances or "jet lag" requires research. Transmeridian flight, which induces phase shifts between the circadian rhythms of the body and the

timing of external environmental synchronizers, often results in non-specific fatigue, insomnia and sleep disturbances, gastrointestinal complaints, headaches, disorientation and irritability. Research is needed to identify individual parameters of the circadian system. It should be determined if these predictive factors, when obtained from simulations, can be extrapolated to predict readaptation and to evaluate possible carry-over influence when duty schedules are frequently changed. This circadian system research should define the mechanisms of circadian phase resetting and the environmental parameters that influence resynchronization. The neurophysiological mechanisms involved must also be established. Based on this understanding, efforts should be made to develop phase resetting drugs and to develop mathematical models of the human circadian system for simulation of mission induced time zone shifts.

Performance Enhancement

Perhaps the primary feature of man that differs from other organisms is his higher order cognitive capabilities (also discussed in Chapter 2) that form the crucial stage between sensory input and enlightened response. Future missions call for examining means to optimize these cognitive processes. That optimization will require research into what cognition really is, how presently defined cognitive skills can be measured and the possible techniques for enhancement as they relate to USAF mission requirements.

Relevant selection criteria need to be established for the individual cognitive and personality characteristics of aircrewmen. Assessment methodologies and instruments need to be developed that validly and reliably differentiate a spectrum of capabilities and styles in terms of cognition, personality functioning, and trainability in specific skills. These can be coupled with mission or aircraft characteristics to provide the best match of man and machine.

Several technical advances in the field of neurophysiology may be applicable to the selection process as well as innovations expected in the next few decades. Since the civilian community will tend to use these only for the detection and correction of pathological processes, it is expected that the USAF will need to direct their use for characterizing features of neural organization and function desirable in fliers and other specialists.

In the past, innate flying skill was demonstrated by performance only. There was, at best, subjective evaluation by flight surgeons of good reflexes and natural athletic ability. A new approach to the problem is to use advanced techniques to identify those elements of neural organization and function which account for having good hands. The new techniques that can be applied to this research are brain electrical activity mapping, BEAM, positron emission transaxial tomography, PETT, and event related cortical evoked response.

Visual Enhancement

Increasing scientific evidence shows that while optical quality is important in target acquisition, the first stages of the retina-brain system can relate to the capabilities of the pilot to see a target under conditions not directly related to optical quality. New visual tests, both developed and under development, need to be related to performance to create more meaningful visual standards. The research into these new visual assessment techniques has suggested that visual enhancement (increasing the ability to discern and identify objects) is possible. A similar research approach is needed for the other sensory modalities (hearing, touch, etc.) to probe these capabilities in terms of validity, control, and measurement. This research should create performance-based sensory standards and enhancements by determining sensory limits within a performance related quantitative framework. These sensory limits should also be related to mission requirements and the technological limits of the aircraft system. Opportunities for sensory enhancement should be identified and their development pursued.

Optimization of Duty Time

A crucial element of both the crew selective process and the enhancement of crew performance is the ability to monitor fatigue. Research is needed to identify the physiological indicators of fatigue and to establish criteria for the onset and degree of fatigue. Instrumentation that monitors fatigue by combining these measurements to provide an index of fatigue can then be developed. This accomplished, further research can be pursued that establishes specific mission related fatigue norms

that can be used to monitor the crew's performance in flight.

In continuous 24 hour per day, year around operations personnel must be scheduled to provide continuous service. Research is needed to provide the sleep-wake cycle information needed to design duty-rest cycles which least disrupt the sleep-wake cycle and minimize deteriorizations in alertness and performance.

While there is currently an opportunity to apply information about the circadian system to current rest-duty schedules, there is an even greater need for basic research to define the oscillator characteristics of the circadian pacemakers that time sleep and wakefulness and that influence the ability of sleep-wake cycles and physiological and psychological function to readjust to changes in phase shift. In particular, a phase response curve for the human circadian system needs to be defined, the arrangement regulating the human sleep-wake cycle needs to be characterized adequately and mathematical models need to be constructed using coupled oscillator features that can predict the limits of schedule tolerance. Basic research also needs to be conducted using animal models to investigate the factors that determine the rate of adjustment to work-rest schedules. In order to provide a reasonable analogy to man these studies should be conducted in animals that are awake during the day and asleep at night.

Information Transfer Enhancement

Data management, decision making, and design of data displays require a secure knowledge of the limits of information registry in various working modes. Existing research efforts are exploring relatively low level problems, whereas magnitude is a critical issue. Control of attention in a negative sense, e.g., meditational skills, is still in an anecdotal stage, but would be useful in fatigue prevention via recovery during rest stages.

Research is needed to define the normal range of focused and nonfocused capacity to store data in short and long term memory. Studies of fluctuations of this capacity due to fatigue and/or physiologically disrupting states, such as transmeridianal, diurnal phase-shifting and/or neuropharmacological impairment of central synaptic function, should also be investigated.

The most troublesome area for practical use of computational aids is the user interface. This is especially critical for man-machine integration in aeronautical systems, where data intake rate and decision consequences are likely to be maximally stressed. Because people vary widely in genetic and acquired skill profiles, system displays are designed for a minimal average crew member. Both crew selection and training narrow the variance in operator skills; nonetheless, by definition of the concept of the average, for the most part matches will be suboptimal to some degree.

A method is needed, then, to fine tune the display and control interface of integrated weapons/control systems so that it matches optimally to operator cognitive style. Flight simulators should be designed such that some degree of parametric control of display rates, size, function and sampling distribution is present. When optimal for a given operator, it should be possible to make an insert card that records the flier's optimal parameters. Insertion of the card into an onboard system controller can then set the preferred parameter profile to optimize his flying performance.

On-Alert Time Enhancement

It is necessary that methods be developed for maintaining a pilot in the alert posture for as long as possible and, at the same time, monitoring when his/her mission completion potential has begun to degrade. Efforts should be made to enhance his alert duration and, as discussed earlier, the optimum duty-rest cycle of the aircrew must be determined.

Psychophysiological research should investigate sympathetic nervous system arousal and determine if this arousal increases or decreases with time. This information, coupled with data from real or simulated launches, can be used to determine the potential effectiveness of missions as a function of on-alert time.

Research into enhancing the number of hours on-alert should consider optimizing schedules and the use of internal enhancement techniques. These techniques may include such relaxation techniques as autogenic training, deep muscle relaxation, autohypnosis and biofeedback as well as such alerting techniques as autohypnosis, mental imaging, and biofeedback.

Morale Enhancement During Combat

At the other extreme from monotonous standing alerts are the psychophysiological disorders associated with combat. The incidence of these disorders increases when morale is low. Research is needed to develop a means of measuring aircrew morale, which is admittedly a very abstract entity. Methods of enhancing aircrew morale before and during combat are needed as are means for preparing the aircrewman for the fear generated by combat.

Reliability Enhancement and Aging

In all situations, the reliability of human operations is less than perfect. Operator reliability research is in its infancy, although provocative progress has recently been made due to its application in C^3I and the nuclear power generating industry. Research is needed to characterize the components of human reliability and to develop a human reliability model that can serve as a tool for studies as C^3I systems evolve.

Related to this are the effects of aging on information processing and decision making effectiveness. C^3I centers vary in size, scope of responsibility, breadth of functions, and level of command. Staff rank and experience increases as each of these factors increase. Within a single center, there are also variations in experience, skills, and rank that have an approximate relationship with age. There are no data on changes or variations in effectiveness, if they occur, in the processes of information processing and decision making with age. Research should be directed toward quantifying the changes in the process and effectiveness of information processing and decision making with experience, rank, and age. Training techniques need to be developed that enhance performance in younger operators if age counts, or, in the older operators if deficiencies develop with age.

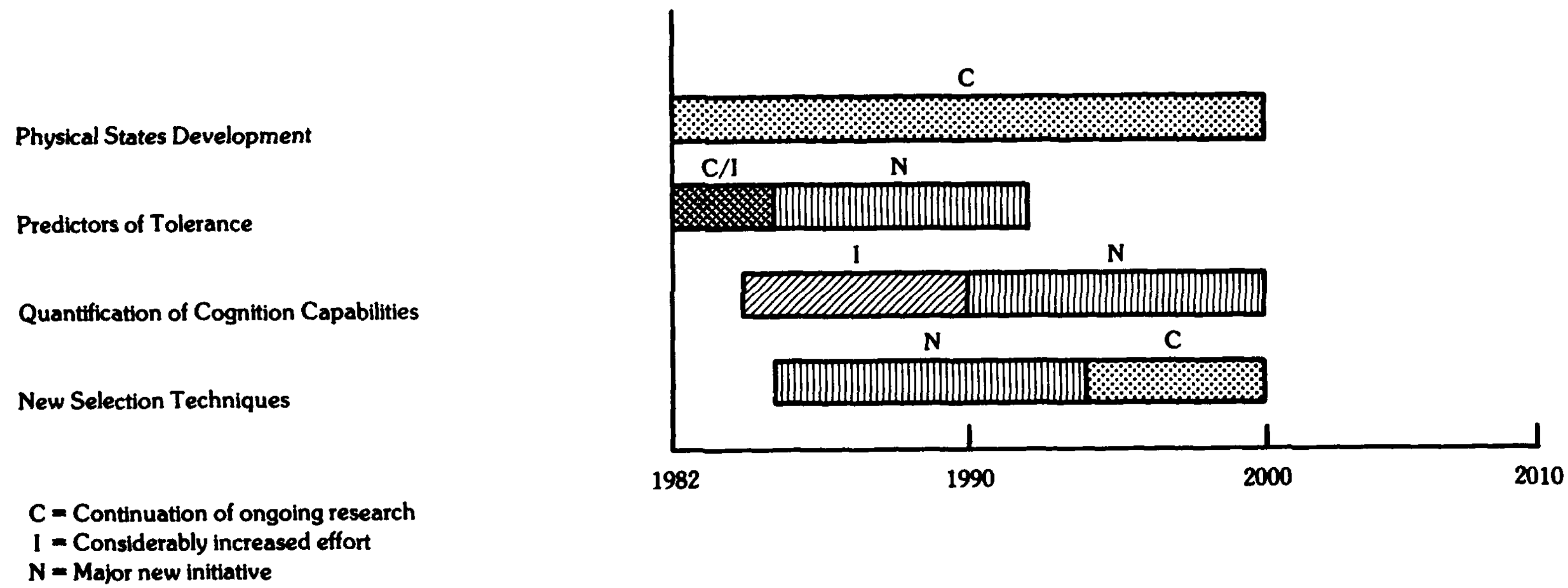


Figure 6
Crew Selection - Future Trends

7

Chemical and Biological Defense

During the past several years, the Air Force has become increasingly aware of the seriousness of the threat of chemical and biological warfare and the importance of environmental toxins, especially during long missions. The Warsaw Pact arsenal devoted to chemical agents, reported use of mycotoxins and other agents in Afghanistan and Laos, and an unexplained epidemic of anthrax in Sverdlosk, USSR, plus voluminous USSR publications on various biological toxins underline the potential threat.

The agents that seem the greatest threat during the next twenty years are organophosphates, vesicant agents, and conventional bacterial warfare toxins. After the year 2000, these agents may be joined by genetically engineered organisms. Genetic engineering may also permit production of known toxins and microorganisms that are currently impractical using conventional production methods. It is also a distinct possibility that novel organisms with altered characteristics will be produced by genetic engineering.

The need exists to incorporate CW/BW defense requirements into the conceptual and engineering design of all Air Force systems. This is particularly true in protecting facilities and personnel involved in C³I functions that are so critical and potentially vulnerable.

Biomedical Research Objectives

Although much is known of the effects of near lethal doses of agents, the effects of low, subacute doses of agents on behavior and mental performance are poorly understood. Research in nonhuman primates is needed to predict the threat to pilot performance. Models need to be established to determine if the efficacy of drugs proposed for counteracting the lethal effects of agents are effective against the mental incapacitation of low agent doses. At this time, basic biochemical and pharmacological data are minimal and, until expanded by further research, these modeling efforts will be severely restricted.

New approaches to the study of prophylaxis and treatment are needed. Specifically, the application of pharmokinetic theory should be applied to studies of dose:response relationships. Classical toxicology has ignored the impact saturable pathways may have on kinetic behavior.

Drug development should be pursued that seeks to protect against CNS incapacitation at low dose levels even if it reduces protection against lethal doses. This will require that highly effective physical protection systems be available.

Three potential levels of protection by drugs are protection against lethal effects, protection against physical incapacitation, and protection against central nervous system incapacitation. The Air Force has a special requirement to protect against functional CNS decrements and should pursue a novel drug development program. Prophylaxis and treatment of agent-exposed crewmen requires research to develop drugs which prevent death, disability and CNS incapacitation without producing performance decrements. This will require animal models which predict qualitatively and quantitatively CNS decrements induced by both agents and potential drugs for both prophylaxis and treatment.

A better understanding of human response to chemical agents must be developed. This research should quantify human physiological and behavioral responses to chemical agents and should develop validated physiological models. These models will require data bases obtained from test animals to predict human responses to agents. Computer simulations using the models will assess the effects of variations in physiological parameters among different mammalian species and the basic biochemical data.

The ultimate product of this research will be the linking of physiological and behavioral measurements into one model. This model will provide the framework to design the necessary experimental protocols for identifying agent response mechanisms. Emphasis should be given to identifying species variations and extrapolation from animals to man based on variations in physiological parameters. Specific studies with these models should consider low level chronic or repeated exposures on visual capacity, respiratory function, the central nervous system, and the cardiovascular system. The interaction of chemical agents and fatigue plus the influence of physical stress and other chemical stresses must also be included in these models.

In order to complete the loop in assessing the response of humans to agents, *in situ* biological indicators of intoxication should be explored for implantation in humans to assess pilot or aircrew performance capabilities.

Physical Sciences Research Objectives

Opportunities exist for exploiting technology developed for environmental and industrial hygiene purposes for agent detection and identification, protection, and decontamination. Detection and identification are needed in order to mount a timely defense against a specific agent. Protection, both individual and collective, is the most effective means of keeping forces operational in a CW environment, but decontamination of the protected crewman and his equipment is mandatory if the crewman is to reach and survive in a safe haven after exposure.

Detection and identification of agents require research in several scientific fields to produce devices that can identify a wide variety of agents. The technologies presently being developed for this purpose are remote infrared sensing, gas chromatography, mass spectroscopy, quartz microbalances, industrial hygiene dosimetry, damp and wet chemistry using multilayer films, and spray on detectors.

To meet longer term requirements, research is needed to explore the applicability of lidar, infrared fibers and sources, miniature gas chromatography, flame photometry, organometallic reactions, immunological approaches and biosensors. In the last category, exploitation of exquisitely sensitive olfactory mechanisms shows promise of distinguishing individual chemical or toxic agents.

In the field of CW/BW protection, the goal of future research should be to improve individual protective ensembles and to provide permanent, hardened collective protection facilities. Basic research in the formulation of semipermeable and nonpermeable materials is needed, especially for hand protection devices. Outer protective garments must be disposable and research and development must place importance on low cost. Above all, the protective assemblies should impose minimal, if any, penalties on the performance of the user.

New concepts of protection also warrant investigation. These include spray/peel off protective skins, self-decontaminating/self-repairing skins and even exotics such as individual energy fields.

Although the goal of the research and development efforts in CW protection is to provide nonencumbering individual protection, it is expected that the current problems of performance degradation will persist. Thermal loading requires that research be carried out on heat dissipating materials and active heat transfer such as liquid-conditioned garments. New visor materials are needed that combine CW protection with those for other aviation hazards while not impairing vision. Respirators, and particularly filters, require improvements in indicating the residual capacity available.

In both individual and collective protective shelter development, a need exists for nontoxic stimulants for assessing both the design and the integrity of shelters . Exploratory development of processing procedures and new analytical methods are needed for assessing contamination and dosage received by individuals entering these collective shelters.

Decontamination research to the year 2000 should be directed toward decreasing dermal

absorption, inhalation. or ingestion of CW agents to negligible levels. Further, methods must be developed that can rapidly decontaminate large surface areas and which are general rather than agent-specific. In personnel decontamination, research is needed to develop methods of determining when skin decontamination is complete, and better, safer decontamination agents are needed.

Research should also be pursued in techniques for decontaminating equipment; electronic equipment is an especially difficult problem. Promising approaches include development of chemicals in the gaseous phase and degasing equipment in a partial vacuum. Ultraviolet light and microwaves are among the promising energy absorptive techniques that should be investigated for large surface area decontamination. The development of new bacteria, antibodies and other receptors that can destroy agents by binding or digesting them is a potentially fruitful area of basic research.

Finally, the development of an operations research capability is needed that can model and integrate the various components discussed in this chapter. The operational models should incorporate the human response to various agents under varying exposure scenarios, alternative personnel and collective protection methods, alternative methods for decontamination, and various detection and monitoring schemes.

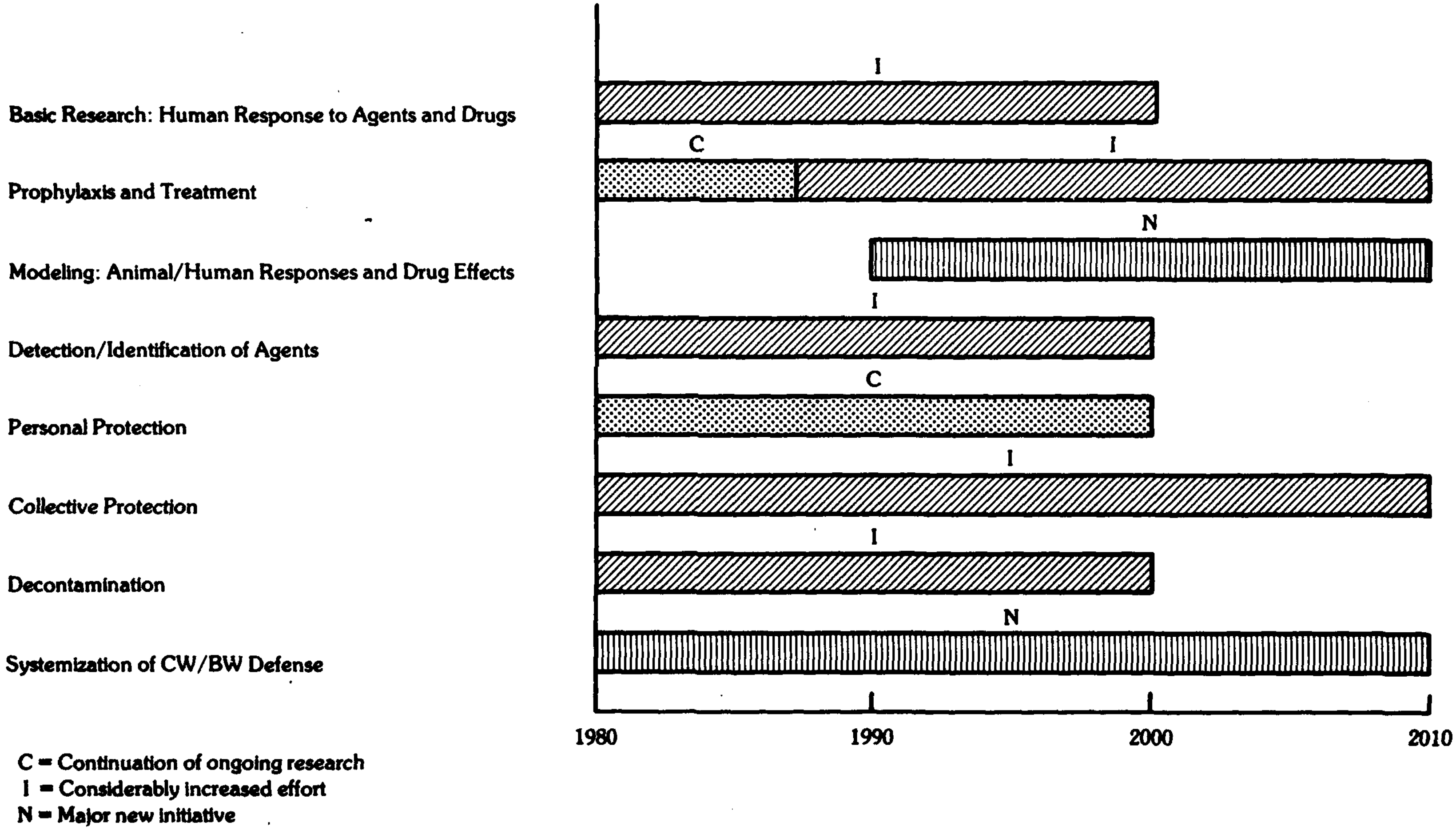


Figure 7
Research Plan: CW/BW Defense

8

Radiation Environment

Electromagnetic and particulate radiation produced by nuclear weapons, high energy lasers, and future high-powered pulsed radio frequency radiation (RFR) systems, represent potential anti-personnel devices for the year 2000 and beyond. Lasers and RFR systems add a new dimension of crew vulnerability that clearly requires protective devices and materials for hardening normal aircraft systems.

Lasers

The use of lasers in military operations is a fact, with the eye as the most susceptible and critical biological target. The most obvious strategy for countering the threat is the development of eye protection, both as personnel equipment and as hardened canopies, windscreens and sensors. The ideal eye protective material or device is one which provides protection against any wave length and pulse width while still allowing transmission of sufficient light to permit the crew to perform critical visual tasks. A method for this does not exist at this time, but progress is being made in the development of narrow band, absorbing and reflective filter materials.

In these development efforts, however, consideration must be given to making cockpit lighting and displays complementary to the protective devices. If new materials are not suitable or adequate for integration into existing cockpits, then alternate means must be developed for providing visual information to the aircrew while still providing eye protection.

Since protective devices are almost always limited in their effectiveness, research is needed to assess visual performance degradation following later exposure and to characterize the potential eye stress produced by developing laser systems. This will include developing and improving visual system performance assessment techniques and, specifically, the visually evoked potential. Behavioral studies should be incorporated into the assessment techniques for studying degradation of visual performance.

The performance of the aircrew when using electro optical sensors and devices that have been degraded by laser radiation also requires research. This research should examine alternate means of providing visual contact with the environment outside the cockpit. This quantification of laser effects on operator performance will require high fidelity man-in-the-loop simulation studies and a strong interaction with the engineering community. These studies should establish "hardening" requirements to enable system designers to reduce vulnerability to laser radiation.

Finally, research is needed to assess the medical implications of laser exposure. Studies are needed in the treatment of severe laser injury to develop procedures for casualty handling and treatment. Also, research opportunities exist for determining the usefulness of laser radiation in the treatment of wounds.

Radio Frequency Radiation

Biotechnology research must consider the significant advances that can be made in electromagnetic radiation weapons and defenses that could be in place by the year 2000. Both offensive and defensive systems will add significant

radiation stress to humans in a wide range of military operations.

Research is first needed to develop and apply methods for assessing pulsed RFR effects. Techniques are needed for depositing RFR at selected organ sites. Mathematical models and physical measurement capabilities must be developed to track, in real time, RFR energy distributions within these organ sites as a function of physiological processes such as diffusion and blood flow. These studies will require prudent extrapolation of physical and physiological data obtained from laboratory animals to humans in operational environments.

After the development of these assessment and measurement methods, research can proceed on the mechanisms of action of RFR on living systems. These interactions must be studied at the molecular, cellular and tissue levels. These studies should specifically address the effects on chemical reaction dynamics, macromolecular reconformations, membrane responses, diffusion coefficients, molecular resonances, microscopic thermal gradients, and RFR induced acoustic phenomena. Methods will be needed to translate these responses measured in laboratory animals to the expected results in humans and to assess how these will affect the operator's performance.

Special research emphasis should be on the disruption of normal physiological functions. The physiological functions of most concern should be the central nervous system, cardiovascular system and the respiratory system. Past experience with electroshock therapy and the increasing understanding of the brain as an electrically mediated organ suggest that RFR can disrupt normal purposeful behavior and may be capable of directing or interrogating such behavior.

Initial attention should be directed toward organ specific thermal loading and electromagnetic field effects. Subsequent work should address the possibilities of directing and interrogating mental functioning to provide a revolutionary capability to defend against hostile actions and to collect intelligence prior to a conflict.

Finally, it may be possible to sensitize large military groups to extremely dispersed amounts of biological and chemical agents. It should be noted that this may only require relatively low level RFR.

Ionizing Radiation

In the event of limited or strategic nuclear weapon use, base escape, deployment, and reconstitution of strategic forces will result in aircrew exposures to delayed, decaying dose rate radiation. This long term exposure to militarily low levels of radiation will also be experienced by long term loitering aircraft such as AWAC. The fractionation and protraction of dose that the aircrew will experience is known to produce a less severe effect than a single acute dose, but the specific performance degradation dose relationships, as a function of time, are not known. Further, the combined effects of other stressors, such as fatigue, must be accounted for in these relationships.

Research is required to define those dose rate schedules that are compatible with sure-safe and probable mission completion. The research program should also strive to establish in these schedules the levels of vulnerability and dose as a function of complexity of duties, i.e., Battle Staff Commander versus other crewman.

Developing methods of identifying, perhaps with biochemical and biological models of radiation injury, aircrews who are sensitive or nonsensitive responders to radiation should be incorporated into the crew selection research discussed in Chapter 6. Ideally, simulations may be developed to validate such models and then to degrade the system and the operator in parallel to determine addition or synergism of effects.

Treatment of radiation casualties from acute and, especially, long duration, low dose rate exposures is and will continue to be a problem due primarily to the uncertainty of the dose received. Research is needed to develop methods of using the crew member's biology as his personal dosimeter. Studies are needed to identify biochemical parameters that will provide an early, accurate indication of the degree of radiation injury sustained. Clinical tests are needed that measure absorbed dose based on biochemical tests that are suitable for use in hospitals, field medical facilities, and in flight by the crewman himself. These, coupled with other methods, should be used to develop procedures for field personnel to use for quickly identifying supralethally irradiated personnel. The research and development of these techniques should consider blood assays, waste

product assays, and hair, fingernails and respiratory system products.

Consideration should be given in future research efforts to development of a premission, orally administered radiation assay substance. Such a benign substance would be expected to react, decompose or rearrange quantitatively when the body is exposed to low levels of radiation. The substance or its by-products must, of course, be quickly and easily measureable.

Nuclear radiation is not the only hazard produced by nuclear weapons. Short duration bursts of electromagnetic radiation appear to be a potential soft kill threat that could degrade or incapacitate the aircrew. Research is needed to develop an understanding of the electromagnetic pulse phenomena and its potential for soft kill. Vulnerability envelopes need to be developed for human operators; and, after understanding its mechanisms of action, countermeasures need to be defined. These research studies should define the threshold levels and vulnerability envelopes for such endpoints as retinal vessel leakage, corneal curvature changes, retrograde amnesia, convulsions and stupor-like states, and collapse.

Protection and treatment of the aircrew exposed to radiation will continue to require research to meet the needs of the year 2000. Research is needed to develop chemical agents or physical means of increasing man's radiation tolerance. Chelating agents need to be developed to reduce absorption of inhaled or ingested fission products.

Radiation therapy research should consider noncontemporary means of bone marrow reconstitution. Such techniques could include endogenous stem cell manipulation, endogenous stem cell replacement, and cloning of universal donor stem cells.

Finally, research is needed to define the mechanism of radiation fatigability. This research should concentrate on testing the hypothesis that the physiologic decrement is related to cellular damage expressed by residual stem cell levels.

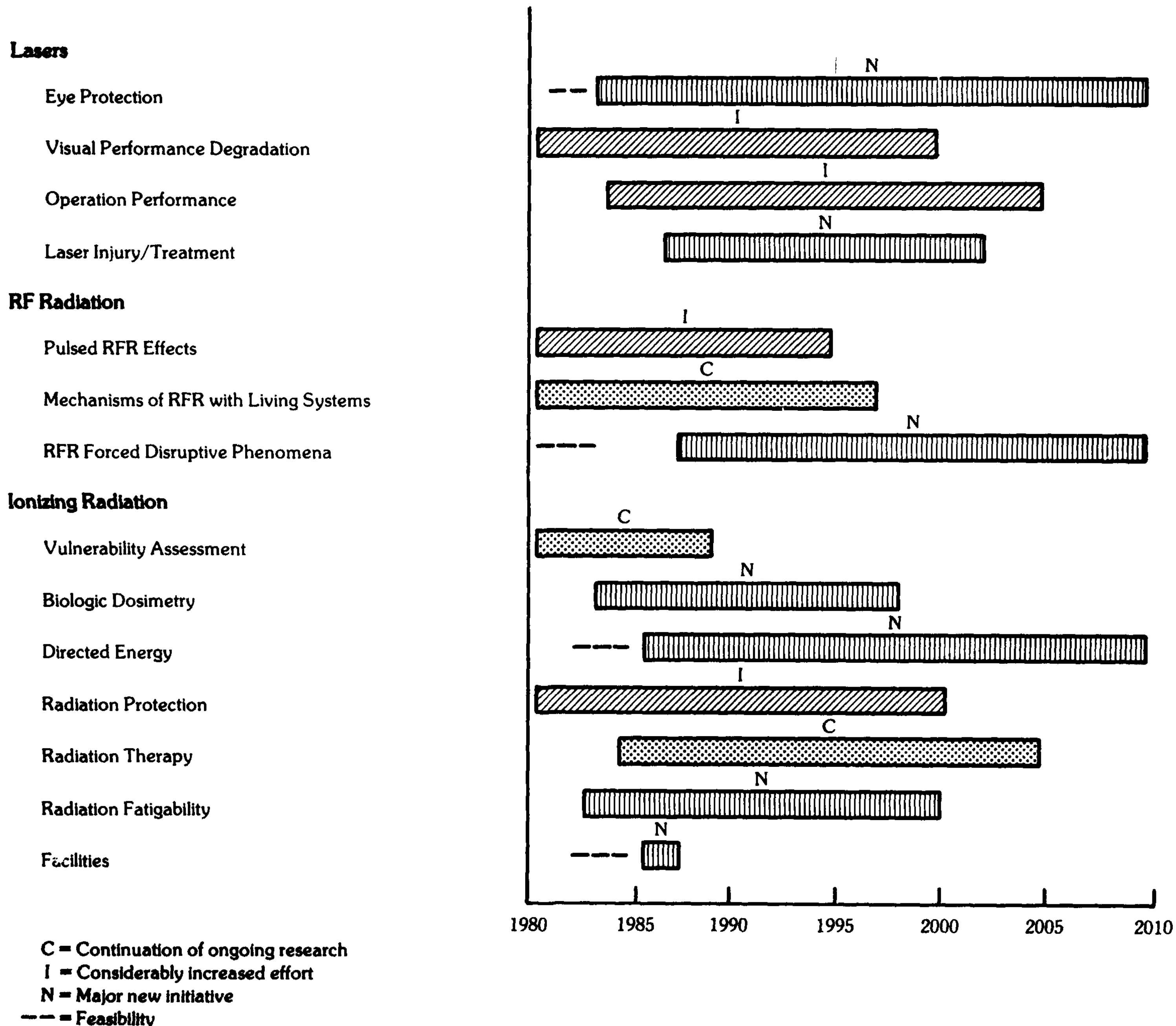


Figure 8
Radiation Environments

Appendices

Appendix A
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Appendix B
Biotechnology Areas of Emphasis for Potential 1990-2020 Manned Aircraft Missions

1. Extraordinarily complex automated people/information systems with human roles biased toward monitoring, supervising and decision making.

   Key Issues:

   How to achieve a symbiotic relationship with automation.

   How to make combat decisions on the basis of symbolically presented battle situations.

   Quantitative understanding of the evolution, propagation and reduction of critical error(s) in people/machine systems.

   Proper methods to alert crew to complex system degradation.

   Determining training and simulation needs for successful operation of degraded systems.

2. High intensity, long-duration, unforgiving missions.

   Key Issues:

   Nature of operator performance degradation, e.g., reduced capacity due to divided attention, complex operations, fatigue.

   Definition of "impaired operator" capabilities to assist system designers to provide back-up modes.

3. Extended biodynamic environment for enhanced performance, e.g., six degree-of-freedom control modes, high G maneuvering, tailored control modes, restraint systems, thermal holding. Accommodation to unexpected maneuvers due to automatic or third party control of aircraft.

   Key Issues:

   Desirable tailored control modes, associated restraint systems, manipulators.

   Escape systems, suits.

   Low profile/observable vehicle display, controls, manipulators, supine, prone, Mini MX VTOL—standing.

   High G maneuvering, low-level prolonged vibration.

   Compensation/cancellation of biodynamic feedthrough on controlled displays.

4. Simulation for system concept design, development formulation and training.

   Key Issues:

   Simulation validity, fidelity (especially of degrading environment), tailoring for critical issues of performance training. Need to validate simulators before actual hardware is available and during design development.

5. Major technological advances in display media, computation and "manipulative" interfaces, e.g., explore voice actuation, evoked response.

   Key Issues:

   Improvement of existing functions.

   "Invention" of new uses of human capabilities for information transfer, presentation and response to massive new information quantity and rates to achieve command or combat decisions.

6. Refinements in crew selection—quantify decision-making capabilities, motivation, maturity, team player competency—find remaining decision capacity under degrading environments.

7. Physical and chemical enhancement as well as impairment of crew-sustained alertness, before and between missions, conditioning, circadian disruption, training sleep skills, biofeedback, avoidance of degrading substances, e.g., drugs, coffee, smoking.

8. Chemical biological attack initiatives (including all toxic agents)—detection, protection, models for chemical effects, including scaling from animal experiments.

9. Ionizing radiation—long duration loiter, residual and acute radiation, neutron weapons. Radiation hazard must also take account of on-board environment.

10. Laser threats—pulsed, high and medium energy, effects on vision re-radiation/flash blindness, optical devices.

11. Other electromagnetic-microwave from own aircraft or from attacker; manipulators.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses the basic biotechnology research problems that require solution by the year 2000 to ensure optimum performance of manned Air Force aeronautical systems. The projected aeronautical systems for strategic, tactical and support systems are discussed, with emphasis placed on the roles of increased automation and information processing, as well as the increased physical stress of higher performance aircraft, extended mission durations and new weapon threats. Six generic areas of biotechnology are considered, along with the research needed to address the needs of the year 2000 aircrew. First discussed is the

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human-machine symbiosis needed in systems that will become extraordinarily complex. This is followed by the related needs in developing improved human-machine information interfaces that avoid overloading the human operator or pilot. Many missions of the future will be unforgiving and of high intensity. The problems and research needed to deal with the increased stress and to protect and enhance aircrews' performance during these missions are discussed in detail. The report discusses how simulators can be advanced to provide not only better training for aircrews, but also how they can be used in the development of new systems for optimizing the human-information-machine relationship. The increasing complexity of aeronautical systems discussed early in the report is complemented by a chapter on crew selection and enhancement. More care and better techniques are needed for selecting candidates for each aircrew position and for enhancing their capabilities in order to maximize their potential for successfully accomplishing their missions. The report is completed by chapters on the problems and research issues facing aircrews who must operate in chemical and biological warfare environments and in radiation environments.

The breadth of topics covered in this study required that the report be published in two volumes. Volume 1 is a very brief summary of the research issues and the proposed research plan. Volume 2 provides, for the interested reader, a more detailed discussion on the background and proposed solutions of each of the research issues.